SOUTHERN GREAT PLAINS 1997 (SGP97) HYDROLOGY EXPERIMENT PLAN

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CONTENTS

0. EXECUTIVE SUMMARY

The Southern Great Plains 1997 (SGP97) Hydrology Experiment originated from an interdisciplinary investigation, "Soil Moisture Mapping at Satellite Temporal and Spatial Scales" (PI: Thomas J. Jackson, USDA Agricultural Research Service, Beltsville, MD) selected under the NASA Research Announcement 95-MTPE-03. The main objective of this investigation was to establish that the retrieval algorithms for surface soil moisture developed at higher spatial resolution using truck- and aircraft-based sensors can be extended to the coarser resolutions expected from satellite platforms. As part of this investigation, a field experiment, built upon the success of a previous experiment of much smaller scale (Jackson et al., 1995), was proposed for 1997. The core of the 1997 experiment involves the deployment of the L-band Electronically Scanned Thinned Array Radiometer (ESTAR) for daily mapping of surface soil moisture over an area greater than 10,000 km2 and a period on the order of a month. Motivated by the wide-spread interest among hydrologists, soil scientists, ecologists and meteorologists in the problems of the estimation of soil moisture and temperature states at the continental scale and the coupling between land-surface and the atmosphere (Wei, 1995), a workshop was held in Beltsville, Maryland, on August 26-28, 1996; the main purpose of this workshop was to identify additional complementary measurements that would promote the overall utility of the experimental data in interdisciplinary research. Further deliberation of the suggestions and recommendations made at the workshop led to the plan described herein which is really the result of the abundant individual and institutional support and cooperation.

The SGP97 Hydrology Experiment as it has developed is a collaboration by a team of interested scientists largely based on existing sponsored scientific investigations and research projects; no science teams were specifically selected for designing and executing the experiment. Cooperation and contributions by many (either individually or as a group), have resulted in a comprehensive opportunity for multidisciplinary scientific research. Research use of the experimental data is encouraged; care is given to data management to allow easy access upon the completion of quality control and cross calibration and validation.

Chapter 1 provides an overview of the scientific issues and objectives of SGP97, the approach taken in designing the experiment, and a summary of key measurements and data products. Chapters 2-5 contains detailed descriptions of the ground and aircraft based data and information to be collected and assembled pertaining to the soils, soil moisture and temperature, vegetation and land cover, as well as the atmospheric boundary layer during SGP97. Satellite data acquisition is described in Chapter 6. This document is expected to be revised as additional details are resolved with a final version expected in June, 1997.

1. OVERVIEW

Soil moisture is fundamental in several disciplines of the Earth sciences. The need for a suitable approach to global measurement of soil moisture has been emphasized, in particular, by the World Climate Research Program (National Research Council, 1992) wherein the Global Energy and Water Cycle Experiment (GEWEX) was created to study the "fast" component of the climate system. One of the objectives of the GEWEX Continental-scale International Project (GCIP) is to improve the predictive capability of coupled hydrologic-meteorological models; an improved capability in modeling the large-scale soil moisture dynamics and its verification is essential.

As in the case of many geophysical variables, global measurement and interpretation of soil moisture might be best accomplished by a combination of spaceborne and ground-based techniques. The SGP97 Hydrology Experiment builds upon the success of the Little Washita 1992 experiment in demonstrating the viability of L-band radiometry for remotely sensing surface moisture. The insight gained from the Little Washita 1992 experiment (e.g., Rodriguez-Iturbe et al., 1996, Mattikali et al., 1996;) and the emerging research needs from GCIP form the basis of the scientific objectives of SGP97.

1.1. Scientific Objectives

The difficulty with the measurement of soil moisture and the understanding of its dynamics has often been attributed to the heterogeneity of soil properties and land surface attributes. However, at the large scale, the complicating factor in soil moisture dynamics also lies with the complex control of the land surface energy and water balance by the atmosphere and the soil; this control is further complicated by plant activities in the root zone.

SGP97 is set in a subhumid environment during early summer. Within this setting, the objectives of SGP97 are

1. to establish that the retrieval algorithms for surface soil moisture developed at higher spatial resolution using truck- and aircraft-based sensors can be extended to the coarser resolutions expected from satellite platforms;
2. to verify spatial-temporal estimators of soil moisture and to examine the utility of pedotransfer function in hydrologic modeling;
3. to examine the feasibility of inferring soil moisture and temperature profiles using surface observations in conjunction with in situ measurements, and
4. to examine the effect of soil moisture on the evolution of the atmospheric boundary layer and clouds over the southern great plains during the warm season.

1.2. Approach

SGP97 was originally conceived as an airborne experiment for daily mapping of surface soil moisture. In expanding its scope to meet interdisciplinary interests, the main considerations in the experimental design have been (1) maintaining as much spatial airborne coverage as possible on a daily basis; (2) nesting when- and where-ever possible to allow observations at a hierarchy of scales; and (3) making maximum use of existing facilities in the area.

The core of this project is the large scale aircraft soil moisture mapping. Within logistic and fiscal constraints, this experiment will attempt to map surface soil moisture over an area of ~10,000 km^2 (order of magnitude larger than previously observed) at a spatial resolution compatible with known data interpretation algorithms (~1 km). The resulting data base would allow the scaling up to projected satellite sized footprints (~10 km) and cover an area large enough to provide over 100 pixels of this size. These data would allow the examination of the information content of coarse resolution data as well as the analysis of the spatial/temporal scales generally utilized in hydrological and hydrometerological models. We will attempt temporal coverage on a daily basis over a period of one month. Logistical issues (rain events and FAA regulations) will result in a some missing days.

Data will be collected using an L band passive microwave mapping instrument called ESTAR which will be flown on a P-3 aircraft. In addition to the L band system we are attempting to include a thermal infrared sensor and a simulator of the AMSR satellite passive microwave radiometer that will be part of the Japanese ADEOS-II platform and possibly the EOS PM.

The temporal analysis will be enhanced by making continuous 24-hour observations using a truck based microwave radiometer system to complement the once-a-day aircraft measurements. This system consists of L, S, and C band single polarization instruments as well as thermal infrared. It would be located at the DOE ARM CART Central Facility which will provide the most comprehensive temporal observations.

This region selected for investigation is the best instrumented site for surface soil moisture, hydrology and meteorology in the world. ***Figure 1*** shows the location and general features. Reasons for selecting this area included established ties with ARS programs and the possibility of integrating this project with other ongoing programs (DOE ARM and Oklahoma Mesonet).

In selecting the **region**, three key facilities play a critical role. They are the ARS facilities in the Little Washita watershed southwest of Chickasha, the ARS facility at El Reno, and the ARM CART Central Facility (CF) near Lamont (see ***Figure 1***). One of the first changes made in the plan was the expansion to the north of the aircraft mapping so that it included the CF. ***Figure 2*** is a Landsat Thematic Mapper (TM) bands 2, 3, and 4 false color composite of the region. This image is from July 9, 1991 and illustrates the typical conditions that might be encountered during SGP97. The red areas are mostly grasses. Whites and blues are areas of harvested winter wheat. Within the study area, there is a transition from mostly grass in the south to winter wheat in the north. There is also a demarcation between the area of interest and the obviously redder area to the east.

The Little Washita Watershed is the most critical study **area** in the project. It has been the focus of extensive hydrologic research for over 35 years. There is an ongoing data collection of unique and relevant data by the Agricultural Research Service, and the experience the local personnel have had in similar studies such as Washita'92 and the Shuttle Imaging Radar experiments in 1994. The watershed is located in southwest Oklahoma in the Great Plains region of the United States and covers an area of 603 sq. km. (***Figure 1***). Landsat TM data (described above) were used to generate ***Figure 3*** which shows many features and details. The climate is classified as sub-humid with an average annual rainfall of 75 cm. Within the watershed there are a total of 42 continuous recording rain gages distributed at a 5 km spacing over the watershed that are called the ARS Micronet system. The rain gage network of the Little Washita Watershed is fully described in Allen and Naney (1991). The topography of the region is moderately rolling with a maximum relief less than 200 m. Soils include a wide range of textures with large regions of both coarse and fine textures. Land use is dominated by rangeland and pasture (63%) with significant areas of winter wheat and other crops concentrated in the floodplain and western portions of the watershed area. Additional background information on the watershed can be found in Allen and Naney (1991) and Jackson and Schiebe (1993). ***Figure 4*** is a collection of photos showing typical field conditions.

Recently the ARS Micronet system has been integrated in a remote data collection system capable of providing nearly real time hourly observations that include the following:

Rainfall
Air Temperature
Humidity
Soil Temperature (5, 10, 15, and 30 cm)

Equipment has been installed at 12 (***Figure 3***) sites to monitor soil moisture at several depths (5, 10, 15, 20, 30 and 60 cm). Soil heat flux at three depths and soil temperature at eight depths will also be measured. Also scheduled are measurements of specific heat capacity, thermal diffusity, and thermal conductivity at four depths.

ARS also operates a grasslands research center at El Reno, OK. This consists of 6000 acres of federally operated grasslands ranging from winter wheat to natural prairie. ***Figure 5*** is a schematic map of the area and ***Figure 6*** is a TM image. In addition to the ready site access and variety of conditions, this site also can provide logistic support and is located approximately half way between Chickasha and Lamont. ***Figure 7*** is a collection of photos showing typical field conditions.

The third facility that will be used is the ARM CF. This area consists of a grassland and a winter wheat field side by side. This facility is extensively instrumented and a great deal of descriptive information can be found on the home page at URL www.arm.gov/docs/sites/sgp/sgp.html. Scaling results to larger regions will be possible using the ARM Extended Facilities (EF). ***Figure 8*** is a TM image of the CF area and ***Figure 9*** is an aerial photo of the CF site available from the ARM web site.

1.3. Summary of key measurements and data products

Location	Oklahoma 97°W to 99°W and 34.5°N to 37°N
	Soil moisture mapping area 50 km x 280 km
	See Figure 1 Regional Map
Dates	Aircraft mapping on a daily basis June 18 to July 18, 1997
Aircraft and Instruments	NASA Wallops P-3 Mapping L band (ESTAR) passive microwave Single beam dual polarization C band Single beam split window thermal infrared LASE
	DOE Cessna Citation TIMS
	PSRO Piper Navajo Chieftain L band radiometer CASI multispectral scanner
	NRC Twin Otter Flux Measurement System
	NOAA ATDD Long-EZ
Satellite Data Acquisitions	Landsat TM
	Russian MIR Priroda Multifrequency passive microwave
	AVHRR
	Radarsat (multiple dates), JERS-1 and ERS
	SSM/I
	GOES
Ground Sampling Activities	Surface soil moisture gravimetric sampling concurrent with aircraft coverage
	Profile soil moisture sampling
	Soil bulk density and surface roughness
	Soil hydraulic and physical properties
	Vegetation classification
	Vegetation parameters
	Flux stations
	Surface thermal infrared
Products	1 km L band brightness temperature (daily)
	1 km soils data base (texture, pedotransfer data)
	1 km AVHRR and NDVI
	1 km surface soil moisture (daily)
	30 m vegetation classification
	30 m vegetation parameters data base
	Gravimetric soil moisture data
	Vegetation parameter samples
	ARS Micronet data (June-July)
	ARS flux station data
Additional Data Sets pending negotiation	NOAA NWS and NEXRAD data products
	DOE ARM data base
	Oklahoma Mesonet
	Landsat TM images acquired

2. SOIL MOISTURE AND TEMPERATURE

2.1. Introduction

Up to now there have been few soil moisture data sets that could in any way represent the types of observations that a satellite observing system might provide. Data were either good quality over short durations and small areas or sparse point samples over large regions. Therefore, hydrologic and climate studies have relied almost exclusively on simulated data sets, which of course are limited by our ability to describe the physical features and processes through a model representation. Since the science of modelling these large systems is still evolving, these models cannot be expected to fully reflect the exact nature of these processes at this stage. The feedback of actual observations, both spatial and temporal, would be a significant contribution to the development of these interdisciplinary studies.

The critical issues we are proposing to address here involve the scales of temporal and spatial observation of surface soil moisture. Specific objectives are: 1) to establish that higher resolution soil moisture-brightness temperature algorithms developed using truck and aircraft sensors can be extended to the coarser resolutions expected from satellite platforms, 2) to examine the spatial and temporal dynamics of surface soil moisture at an order of magnitude greater than previous investigations, and 3) to develop a data base for soil hydrology and land atmosphere interaction investigations.

2.2. Electronically Scanned Thinned Array Radiometer (ESTAR)

L band passive microwave radiometers are capable of providing surface soil moisture maps. Recent experiments such as Washita'92 (Jackson et al., 1995) have demonstrated the capabilities of this approach. Further information on the approach can be found at **URL hydrolab.arsusda.gov/RSatBARC/soilmoisture.html**

The electronically scanned thinned array radiometer (ESTAR) is a synthetic aperture, passive microwave radiometer operating at a center frequency of 1.413 GHz and a bandwidth of 20 MHZ. As installed it is horizontally polarized. This instrument is the most efficient mapping device currently available.

Aperture synthesis is an interferometric technique in which the product (complex correlation) of the output voltage from pairs of antennas is measured at many different baselines. Each baseline produces a sample point in the Fourier transform of the scene, and a map of the scene is obtained after all measurements have been made by inverting the transform. ESTAR is a hybrid real and synthetic aperture radiometer which uses real antennas (stick antennas) to obtain resolution along-track and aperture synthesis (between pairs of sticks) to obtain resolution across-track (Le Vine et al., 1994). This hybrid configuration could be implemented on a spaceborne platform.

The effective swath created in the ESTAR image reconstruction (essentially an inverse Fourier transformation) is about +/- 45^o wide at the half power points. The field of view is restricted to +/- 45^o to avoid distortion of the beam but could be extended to wider angles if necessary. The image reconstruction algorithm in effect scans this beam across the field of view in 2^o steps. The beam width of each step varies depending on look angle from 8 to 10^o, therefore, the individual original data are not independent, since each data point overlaps its neighbors. Contiguous beam positions can be achieved by averaging the response of several of these data points. This results in approximately nine independent beam positions. Another approach to using the data, especially in a mapping mode, is to interpret each of the original nonindependent observations as a sample point and then use a grid overlay to average the data. The final product of the ESTAR is a time referenced series of data consisting of the set of beam position brightness temperatures at 0.25 second intervals.

Calibration of the ESTAR is achieved by viewing two scenes of known brightness temperature. By plotting the measured response against the theoretical response, a linear regression is developed that corrects for gain and bias. Scenes used for calibration include black body, sky, and water. During aircraft missions, a black body is measured before and after the flight and a water target during the flight. Water temperature is determined using a thermal infrared sensor. The match in level and pattern is quite good and in general the ESTAR calibration should be considered accurate and reliable. For interpretation purposes it should be noted that the sensitivity of soil moisture to brightness temperature is 1% for 3^{o}K.

The ESTAR instrument will be flown on a P-3 aircraft operated by the NASA Wallops Flight Facility. Additional details on the aircraft can be found on the **URL http://www.wff.nasa.gov/**. Current assignments show that the aircraft will be available for flights in Oklahoma from June 18 and July 18, 1997. Instrument installation and check flights will be conducted at Wallops between June 9 and 16. In addition to the ESTAR, a two channel single beam thermal infrared radiometer will be flown. ESTAR will be installed in the bomb bay portion of the aircraft.

Flights will be conducted at an altitude of ~ 7 km and, therefore, the aircraft will be pressurized. It should be noted that radiometer calibration is based on its operating environment. At a particular aircraft altitude this is quite stable, however, operating at drastically different altitudes (and associated thermal environments) requires a separate calibration. All P-3 flights will be conducted at a single altitude to avoid this problem. ***Figure 10*** shows the current flightline plan and Table 1 presents the details.

Table 1. P3 Flightlines							
Line	Start		Stop		Alt. (km)	Length (km)	No. of Flights
	Latitude	Longitude	Latitude	Longitude			
1	37.0000	-97.6275	34.5000	-98.3400	7	280	25
2	34.5000	-98.2225	37.0000	-97.5100	7	280	25
3	37.0000	-97.3925	34.5000	-98.1050	7	280	25
4	34.5000	-97.9875	37.0000	-97.2750	7	280	25
5	37.0000	-97.2750	38.1400	-96.9133	7	130	4*
6	34.9000	-98.3600	34.7800	-98.3500	1	13	4

The same flights will be conducted daily (conditions permitting). Certain antecedent conditions may cause a change in the flight schedule. Nominal over target time will be 9:30 to 11:30 am local time. The decision to fly will be based on the following sequence of conditions; safety regulations (Aircraft Manager), aircraft operation (Aircraft Manager), ESTAR operations (Le Vine), weather conditions affecting flights (Le Vine and Aircraft Manager), experiment objectives (Jackson). In the past, the aircraft has been stationed at Will Rodgers Airport in Oklahoma City. The expected resources required for the aircraft area listed in the Table 2.

Table 2. P3 Flight Hours	
Total area (40 km x 280 km)	11,200 km^2
Altitude	7 km
Resolution ~ 0.8 km Swath ~ 10 km	
Total Lines	4
Air Speed (350 mph)	615 km/hr
Time Required per day	
4 lines (4*0.45 hours)	2.2
To and from site	0.8 hrs
TOTAL	3 hrs/day
Mission Hours	
25 days * 3 hrs/day	75 hours
CASES (1 hours *4 days)	4
Transit	8 hours
TOTAL	87 hours

2.3 C Band Dual Polarization Observations

Two C band radiometers (wavelength of 6 cm) are being leased from Geoinformatics. These will be incorporated into the P3 and an appropriate data collection system by the University of Massachusetts. One antenna will be oriented for H polarization and the other for V polarization. Both will look behind the aircraft at an angle of 50 degrees to simulate future satellite systems. Data is time integrated for a single swath with a width of 5 km at the proposed altitude of 7 km. Data will be collected on all ESTAR P3 lines. The flightlines have been arranged to attempt to fly directly over the critical sampling sites.

2.4 Scanning Low Frequency Microwave Radiometer (SLFMR)

The scanning low frequency microwave radiometer (SLFMR) was designed and built for NOAA to measure ocean surface salinity from a small-engine aircraft by Quadrant Engineering, Inc. This is a 1.4 GHz L Band microwave radiometer. with its own GPS receiver. This will be flown on a Piper Navajo Chieftain aircraft operated by the Provincial Remote Sensing Office (PSRO) in Canada. There is only a limited time frame that this aircraft can be on site (operating out of Oklahoma City), probably the last week of June. The number of flight hours is also very limited. CASI (described in a later section) will also be flown on this aircraft.

The SLFMR has an electronically steered antenna beam and is capable of viewing any of six footprints across the flight track. Footprint size is nominally 0.3 of the altitude. The total swath covered is approximately 2 times the altitude. Since this instrument was designed for salinity mapping the sensitivity and thermal resolution are high. Components of the system which must be placed outside the aircraft are housed in a thermally controlled and aerodynamically shaped enclosure measuring 0.2 m high by 1 m wide by 1.5 m long and weighing 52 kg (115 lbs.). Components of the system which are placed inside the aircraft include a power supply, an IBM compatible computer which is used for control and acquisition of the microwave, infrared and GPS data. The computer, GPS and power supply are mounted in a rack measuring 0.7 m high by 0.5 m wide by 0.5 m long and weighing 32 kg. The infrared radiometer views the surface through a 0.15 m diameter hole in the underside of the aircraft. The infrared radiometer measures 0.2 m high by 0.15 m wide by 0.08 m long and weighing 2.3 kg. The system operates from standard 115 VAC power and requires a maximum of 320 W during normal operation of which 200 W is allocated to the computer and another 70 W is allocated to thermal control of the SLFMR electronics. The system can be placed in a fast warmup mode during which it would require a maximum of 1600 W.

The primary objective of the SLFMR is to provide multiscale L band observations. With the limited hours, it is necessary to focus on a single area (El Reno because it is closest to the airport and has the most concentrated variety of conditions and sampling). The proposed flightlines are described in Table 3. These would be flown twice over the course of one week. Any increase in operating hours could be used to either have more flights at this area or adding a second area.

Table 3. PSRO Piper Navajo Chieftain Flightlines						
Line	Start		Stop		Alt. (km)	Length (km)
	Latitude	Longitude	Latitude	Longitude		
1	35.5435	-98.1100	35.5435	-97.9500	0.5	15
2	35.5515	-97.9500	35.5515	-98.1100	0.5	15
3	35.5595	-98.1100	35.5595	-97.9500	0.5	15
4	35.5675	-97.9500	35.5675	-98.1100	0.5	15
5	35.5475	-98.1100	35.5475	-97.9500	1.0	15
6	35.5635	-97.9500	35.5635	-98.1100	1.0	15
7	35.5555	-97.9500	35.5555	-98.1100	2.0	15
8	35.5555	-97.9500	35.5555	-98.1100	5.0	15

2.5. Thermal Infrared Multispectral Scanner (TIMS)

TIMS is a simulator for the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), an imaging instrument that will fly on EOS AM-1, a satellite planned for launch in 1998 as part of NASA's Earth Observing System (EOS). ASTER will be used to obtain detailed maps of surface temperature. Such information can then be used in studies of the surface energy balance, plant evaporation and evapotranspiration, vegetation and soil characteristics, and the hydrologic cycle.

TIMS is a six channel NASA aircraft scanner operating in the thermal infrared (8 to 12 / m) region of the electromagnetic spectrum. The channels and bandwidths (in microns) are; 1(8.2 - 8.6), 2 (8.6 - 9.0), 3 (9.0 - 9.4), 4 (9.4 - 10.2), 5 (10.2 - 11.2), and 6 (11.2 - 12.2). The instrument has a 2.5 mrad IFOV, 77° FOV spread over 638 pixels. The scan rate can be varied from 7.3 to 25 scans/second in four steps. Typical swath width and resolutions are

For calibration, the system is equipped with cold and warm reference sources or black bodies, approximately covering the temperature range of interest. All pixels are assigned a digital count value between 0 and 256 (DN). Reference source 1 is scanned at the beginning, and the second at the end of a line.

The TIMS instrument is flown on a DOE Cessna Citation aircraft. Eight flight hours are being provided by the EOS project. It is anticipated that the mission will consist of two days of coverage over the course of one week with differing antecedent conditions. Data collection will focus on collecting data over areas with intensive flux station measurements. It is anticipated that the aircraft will base out of Oklahoma City and be on site for one week, either the last week of June or the first week of July. Ideally, these flights should be integrated with the higher resolution L band flights of the SLFMR on the PSRO aircraft.

There are two planned flight lines (Table 4) for the Cessna Citation with TIMS during this summer's Great Plains Experiment in Oklahoma. One line will cover the El Reno test area, just west of OK city, and the other will be over the CART-ARM central facility. The altitude for these lines will be 16,000 feet (5000 m) above ground, yielding a spatial resolution of about 12 m and a useable swath of 5.6 km (+/- 30 deg), resolution of 12 m. The El Reno flight line will cover winter wheat fields south of the ARS rangeland. The CART-ARM line will go directly over the central site and will provide coverage to 3 km on both sides. There would be 3 flights per day, the first 1 hr after sunrise or about 6:00 AM LST; the second at about 10:30 LST, the time of ASTER overpass; and third at the times of the AVHRR overpass, or about 2 to 3 PM (LST) in the afternoon if resources permit.

For the water target coverage at will be obtained at several altitudes (5000', 10000' and 16000' AGL) as the aircraft takes off out of Oklahoma City. This coverage will be obtained at least once a day.

Table 4. DOE Cessna Citation Flightlines

Line	Start		Stop		Area
	Latitude	Longitude	Latitude	Longitude	
1	35.4666	-98.0475	35.6333	-98.0475	El Reno
2	36.5000	-97.4842	36.7500	-97.4842	Central Facility
3	35.1500	-98.4417	35.2500	-98.5400	Lake Cobb

2.6. Split Window Thermal Infrared Radiometer (SWTIR)

The Split Window Thermal Infrared Radiometer is a two channel instrument that collects data along a single swath. It will be installed on the P3 and integrated into the ESTAR data collection system.

2.7. Soil Moisture Sampling

2.7.1 Surface Soil Moisture Sampling

2.7.1.1. Site Selection

Soil moisture observations in SGP97 will be used to address the following objectives of various investigators;

1. Validating and calibrating hydrologic and GCM land processes models
2. Atmospheric boundary layer interactions
3. Verification of the ESTAR microwave radiometer soil moisture algorithm
4. Geostatistical and scaling studies
5. Development of C band microwave radiometer-soil moisture relationships
6. Enhanced calibration of the existing insitu profile systems
7. Correlation of the insitu near surface observation and gravimetric sampling
8. Surface to profile extrapolation
9. Evaluation of alternative soil moisture measurement devices

Items 6 to 8 build on the extensive networks that already exist as part of the DOE ARM, USDA ARS, and Oklahoma Mesonet programs. These efforts will provide a vital link for larger scale and longer term satellite and modeling studies. Analyses will be conducted cooperatively with scientists from these organizations.

The sampling strategy is influenced by some important logistic issues which include the existing and proposed locations of instrumentation (i.e. the insitu profile soil moisture networks), facility support (ARS Little Washita, ARS El Reno, and the ARM Central Facility), and site access. This set of potential sites can be increased to a limited degree to address specific issues related to the items listed above. This is when other factors such as time (all surface samples must be collected within a window of about 3 hours) and manpower resources must be considered.

Data collection and sample coding will be related first to an area; Little Washita (LW), El Reno (ER), and Central Facility (CF). For each area there will be a two digit site code, i.e. LW01. The following table is the current set of sampling sites.

Table 5. SGP97 Soil Moisture Sampling Sites

Site	Description	Network	Type	Cover	Soil	Insitu Profile	Profile Var. Site	Surface Var. Site	Soil Core Sample	Flux Station Site
LW01	BERG	S	P	R	SiL	X			1	
LW02	NOAA	S	F	R	L	X	X	X	1	X
LW03	EF26	A	F	R	LS	X	X	X	1	X
LW04	Adj. EF26		F	R	LS					
LW05	Adj. EF26		F	R	LS					
LW06	R133	S	P	R	SL	X				
LW07	APAC	M	F	R	SiL	X	X		1	
LW08	EF24	A	F	W	SiL	X	X	X	1	X
LW09	R149	S	P	R	SiL	X				
LW10	R146	S	P	R	LS	X				
LW11	R136	S	F	R	L	X	X	X	1	
LW12	Adj. R136		F	R	L					
LW13	Adj. R136		F	R	L					
LW14	Adj. R136		F	R	L					
LW15	R144	S	P	R	L	X				
LW16	R159	S	P	R	SL	X				
LW17	ACME	M	P	R	SL	X			1	
LW18	R154	S	P	R	LS	X				
LW19	R162	S	P	R	SL	X				
LW20	WW		F	W	SiL			X	1	
LW21	Adj. WW		F	W	SiL					
LW22	Adj. WW		F	W	SiL					
LW23	Adj. WW		F	W	SiL					

Network: S-ARS SHAWMS, M-Mesonet, A-ARM EF
Sampling Type: F-Full, P-Profile Only
Cover: R-Range, W-Wheat

SGP97 Soil Moisture Sampling Sites										
Site	Description	Network	Type	Cover	Soil	Insitu Profile	Profile Var. Site	Surface Var. Site	Soil Core Sample	Flux Station Site
ER01	W Hill	S	F	R	SiL	X	X	X	1	X
ER02	Hill		F	R	SiL					
ER03	Silo		F	R	SiL					
ER04	Sewage		F	R	SiL					
ER05	13	M	F	R	SiL	X			1	X
ER06	14		F	R	SiL					
ER07	15		F	R	SiL					
ER08	16		F	R	SiL					
ER09	1,2		F	R	SiL					
ER10	WW		F	R	SiL	X		X	1	X
ER11	Adj.. WW		F	W	SiL					
ER12	Adj.. WW		F	W	SiL					
ER13	Adj.. WW		F	W	SiL					
ER14	KING		P	W	SiL	X			1	
CF01	EF15	A	F	R	SiL	X	X		1	X
CF02	EF16	A	F	W	SiL	X	X		1	X
CF03	WW		F	W	SiL			X		
CF04	Adj.. WW		F	W	SiL					
CF05	Adj.. WW		F	W	SiL					
CF06	Adj.. WW		F	W	SiL					
CF07	WW		F	W	SiL					
CF08	WW		F	W	SiL					
CF09	WW		F	W	SiL					
CF10	WW		F	W	SiL					
CF11	MARS	M	P	R	SiL	X			1	

2.7.1.2. Sampling Plan

2.7.1.2.1. Gravimetric Surface Sampling

For the most part, sampling will be performed on sites approximately a quarter section (0.8 km by 0.8 km) in size. Attempts will be made to sample several adjacent sites that can be clustered. In addition, some sites are being sampled solely for surface-profile correlations and consist of the area immediately surrounding a profile location.

Sites with “Full” sampling will involve two transects separated by 300 m with a sample every 100 m resulting in 14 samples per site. Profile only sites will consist of 9 samples collected over a 30 m by 30 m grid near the profile location. A standardized tool will be used to extract a sample of the 0-5 cm soil layer. Sample location is not critical in this approach. The grid is used only as an aid in stratifying the distribution of samples.

2.7.1.2.2. TDR Surface Sampling

The primary objective of the Southern Great Plains 1997 (SGP97) Experiment is to map soil moisture (0-5 cm surface soil layer) using an airborne passive microwave radiometer. These daily, 1 km^2 resolution, measurements are not detailed enough to capture the high degree of variability exhibited by soil moisture in both space and time. This variability must be better understood to enable full utilization of the larger-scale remotely sensed averages. Therefore, to assess these variations over large areas the remotely sensed observations must be combined with high resolution ground based monitoring. The SGP97 experiment offers a unique opportunity to characterize soil moisture variability at high spatial resolution and determine how well that variability is represented in 1-km (approximately) remotely sensed soil moisture maps. Selected fields will be more intensively sampled using a fixed grid and a time domain reflectometry (TDR) device. The choice of technique is under investigation.

Variability sites will be collocated with gravimetric sampling sites. To the degree possible (allowing for logistics, access to private lands and collocation with other equipment), selection of these quarter sections should reflect the range of variability in surface conditions (e.g. in topography, soils, vegetation, precipitation) encountered within the region, while at the same time providing adequate spatial coverage across the experimental domain. Quarter section sites will lie within three focus areas (Little Washita El Reno, ARM-CF). Studies of horizontal variability will be concentrated within the Little Washita basin. The number of sites will depend upon several factors that should be resolved shortly (number of instruments, time required for measurement, and personnel available).

A detailed study of horizontal variability is critically dependent upon a fast, portable sampling technique. Three TDR-based sensors are currently under consideration, including models offered by Campbell Scientific, Delta-T and Mesa. The feasibility of using of each of these in portable mode is under investigation at Alabama A & M University in conjunction with the Global Hydrology and Climate Center.

Basic gravimetric sampling of quarter sections will consist of 12 samples in the 0-5 cm soil layer (2 parallel rows of 6 samples/row). Supplementary sampling in support of this variability investigation will utilize a grid-based sampling scheme. Forty-nine samples will be collected on a 7 x 7 square sampling grid (approximately 100 m between sampling points) centered within the quarter section. Sampling locations will be marked in the field with spray paint and accurately located using GPS. Additional samples can be taken in more variable regions within quarter sections. This basic sampling plan will be repeated in each of the four sections at full section sites. The same plan could also be repeated for the remaining quarter sections within a subwatershed, or could be modified if the subwatershed is too large. The final sampling plan for the subwatershed is TBD until it is selected. The time frequency of the horizontal variability sampling is TBD and depends upon the method of sampling chosen and the rate at which that sampling can be conducted.

Equipment required for each observing package will include; surface portable TDR units (including TDR sensor, sensor reader, data recorder), GPS unit, utility belt and pouch (manufacturers TBD), Recorder-PC interface cables and extra TDR sensors.

2.7.1.2.3. Bulk Density and Surface Roughness

Bulk density is used to convert the gravimetric samples to volumetric. A standard volume extraction technique will be used. Sampling will be performed by a single team and include 4 samples per site. Surface roughness will be recorded using a photograph of a grid board that will later be digitized. One bulk density sample will be retained per site for possible laboratory soil texture characterization.

2.7.2. Profile Soil Moisture and Temperature Sampling

As noted in Schneider and Fisher (1997), the SGP region is rich in observations, including three research networks: the Department of Energy's Atmospheric Radiation Measurement Program's Southern Great Plains Cloud and Radiation Testbed (ARM/CART SGP Site; Stokes and Schwartz, 1994); the Oklahoma Mesonet (jointly operated by the Universities of Oklahoma and Oklahoma State; Brock, et al, 1995); and the USDA/ARS Micronet in the Little Washita watershed (Elliott, et al, 1993). It was generally agreed that the data from these networks would be more valuable to scientists if the networks were augmented with continuous, automated measurements of volumetric soil water through and below the rooting zone. Each network has made significant progress toward this (Schneider and Fisher, 1997).

All of these networks employ the same type of soil water sensor, the Campbell Scientific Inc. heat dissipation sensor (Model 229-L). Analysis indicated that the CSI 229-L sensor produces reasonable measurements of matric potential over a wide range of wetness, and responds quickly and accurately to changing soil wetness conditions. These evaluations have since been corroborated by Reece (1996). The 229-L also measures soil temperature before each soil wetness measurement cycle. And it is a simple device, with an expected unattended field lifetime greater than 5 years.

The CSI 229-L sensor is designed to produce a point measurement of soil matric potential (the tension with which water is held onto the soil particles) by measuring the temperature change after a heat pulse is introduced (hence "heat dissipation"). This is a distinctly different measurement from the layer average of volumetric water produced by gravimetric measurement, neutron probes, or time domain reflectometry [TDR] systems. Matric potential can be related to volumetric water, given a soil water retention curve (unique for each soil). Thus, computation of volumetric water from the 229-L measured temperature change requires: a) laboratory calibration of each sensor to relate observed temperature changes to water matric potential; and b) determination of the soil water retention curve for the soil surrounding each sensor.

Alternatively, the raw data (temperature changes) could be calibrated against collocated direct measurements of volumetric water. This second route would require a longer calibration period, and would need to be repeated whenever a sensor is replaced in the field.

2.7.2.1. DOE ARM CART

DOE ARM CART refers to the soil moisture systems as Soil Water and Temperature System, or SWATS. To create a minimal redundancy, as well as an opportunity to examine local variability, they deployed the sensors in two profiles, separated horizontally by 1 m. The SWATS takes observations once every hour, with data transmitted automatically via phone line every 8 hours. Data is also stored locally, and manually downloaded during biweekly maintenance checks.

The final design consists of electronics in a surface-mounted enclosure (data logger, multiplexor, constant-current source, power supply, storage module, and telecommunications equipment) supporting 16 CSI 229-L sensors, deployed in two profiles of 8 sensors each. Sensors are located at depths of 5, 15, 25, 35, 60, 85, 125, and 175 cm, rock permitting. The installation procedure was designed to minimize the disturbance of the soil, and maximize the contact between the sensor and the surrounding soil, while satisfying DOE Safety requirements.

The Department of Energy's ARM/CART SGP Site is centered near Lamont, OK, and covers an area roughly 325 by 275 km, extending from the Little Washita watershed in Oklahoma north into central Kansas. The data produced by the SGP Site is part of the DOE contribution to GCIP. The SGP Extended Facilities are of particular interest to GCIP: 22 installation providing observations of air temperature, wind speed and direction, humidity, rainfall, and snow depth; several measures of up welling and downwelling visible and near-infrared radiation; and estimates of sensible and latent heat fluxes in the atmospheric surface layer. SWATS have been added to each of these Extended Facilities.

These instruments are still undergoing calibration. Data for all ARM sites will be available, however, there are four ARM Extended Facilities that will receive more attention for the current study; the two at the Central Facility, EF24, EF26, and the planned installation at El Reno. Locations of these stations are shown in ***Figure 1***.

2.7.2.2. USDA ARS SHAWMS

SHAWMS stands for Soil Heat and Water Measurement System. These sensor packages are managed by Pat Starks and installed within the Little Washita as shown in ***Figure 3*** (12 sites) and at the El Reno facility (4 locations collocated with flux stations, exact locations TBD). Each system includes 3 sensors at 5 cm, then single sensors at 10, 15, 20, 25, and 60 cm. Readings are acquired every hour, and are calibrated against the capacitance probe measurements. These data are downloaded once a week. Data for May through August will be made available to the SGP97 data base. Any additional data must be independently negotiated with Pat Starks (USDA ARS El Reno)

2.7.2.3. Oklahoma Mesonet

Two types of soil water sensors have been added to 60 of the 114 stations comprising the Oklahoma Mesonet. The CSI 229-L has been installed at depths of 5, 25, 60, and 75 cm. Particle size analyses have been conducted for each of these sites. The 229-L sensors are read by a data logger every 30 minutes, and the data are reported in real-time as part of the Mesonet data stream.

The second type of sensor is a time domain reflectometry (TDR) system, the Environmental Sensors MoisturePoint probe, installed to a depth of 90 cm. A Model MP-917 instrument is carried to the site, connected to the probe, and then used to make readings of volumetric water content in 5 soil layers (0-15, 15-30, 30-45, 45-60, and 60-90 cm). Because of the manual nature of the measurement, the TDR observations are made fairly infrequently (whenever a Mesonet technician or interested researcher visits the site). The TDR measurements will be used to perform site-specific, in situ calibration of the 229-L sensors.

Data from this network will be available as part of the data set for the project. The following sites fall within the aircraft mapping area; ACME, APAC, ELRE, KING, and MARS.

2.7.2.4. Cross Calibration with TDR Probes

As noted in Schneider and Fisher (1997), the method most frequently used to calibrate heat dissipation sensors involves the use of high-pressure vessels. Unfortunately, this method requires expensive, specialized equipment and facilities which are not commonly available. Therefore, they are testing several methods in order to develop an alternative method employing readily available equipment, with the goal of providing an efficient and accurate means of calibrating the 229-L sensors before field deployment. The methods differ in the way water potentials are generated, measured, and imposed on the sensors. All sensors deployed in the ARM/CART SGP network have been calibrated using the vapor pressure method, with a number of sensors cross-calibrated to support comparison of the methods. This calibration study is being conducted in collaboration with scientists at the Oklahoma Mesonet.

Schneider and Fisher (1997) reported that data quality analysis is just beginning. Current indications are promising: there is clearly a signal in the raw (temperature change) data associated with rain events and drying, with the expected trends and differences between depths. Scientists at OSU are making pairs of gravimetric measurements at each SGP SWATS Site, one during a relatively wet period, the other drier. Those results will provide a preliminary indication of the accuracy of the 229-L estimates of volumetric water.
There are also longer term plans for the collocation of instruments.

With the variety of installations and the potential problems in calibration the heat dissipation sensors, scientists in Oklahoma had initiated a program utilizing insitu TDR probes that are read on site. The technique used involves Moisture Point probes. A very extensive description of this technique can be found at the following web site **(URL www.esica.com)**. The use of these probes will provide both individual site calibration and some cross calibration. As part of the current project, the number of sites will be increased and observations will be made every day. In addition, at selected sites (see Table 5 for possible locations, however, this is still TBD) additional probes will be installed to examine the spatial aspects of these point probe observations.

2.7.2.5. Dielectric Profiling Stations

HSCaRS will install up to 6 supplemental soil profile stations. Two of these stations will be installed at the Central Facility, one on grass and the other on winter wheat. The remainder will be installed at sites TBD within the Little Washita area. Installation involves digging a pit (about 1 m x 1 m x 1 m) for instrument installation. Soil moisture and temperature measurements will be made at several depths down to about 75 cm in each pit. Soil moisture will be measured using Water Content Reflectometers (Campbell Scientific, Inc), a device based on time domain reflectometry, and using Soil Moisture Probes (Radiation and Energy Balance Systems), a device based on electrical resistance. Soil temperature will be measured in each pit using soil thermistors. Ground heat flux will be determined using a heat flux plate installed at 5 cm depth plus the heat storage in the upper 5 cm layer calculated from the time rate of change of temperature, which is measured using 4-sensor averaging thermocouple probes installed at 1, 2, 3, and 4 cm depths. Techniques to derive the soil dielectric constant from Water Content Reflectometers (or similar sensors) are currently under investigation. If these prove feasible, dielectric constant profiles will be provided at one or more of the profile stations. Stations operate from battery power. These stations will have to be installed approximately one month prior to the experiment.

2.8. Truck Based Microwave Radiometer System

The S and L Microwave Radiometer (SLMR) is a dual frequency passive sensor system operating at S band (2.65 GHz or 11.3 cm) and L band (1.413 GHz or 21.2 cm) managed by the ARS Hydrology Lab and maintained in cooperation with the University of Massachusetts. The staging platform used is a 1990 Navstar hydraulic boom truck belonging to the Hydrological Sciences Branch at NASA's Goddard Space Flight Center. This vehicle is equipped with a hydraulic boom which permits deployment of sensor packages up to a height of approximately 19 m above the ground. The instrument platform at the end of the boom can be moved to vary incidence angle from 0^o (nadir) to 180^o (sky), while the boom itself can be rotated 360^o in azimuth. The antennas are mounted to observe horizontal polarization. At the nominal operating height of 7 m with the specified field of view of the radiometers (20^o), the footprint size is on the order of 2.5 m at a viewing angle of 10^o off nadir. Incidence angle is provided by internal inclinometers.

Recently, a 6 channel stepped-frequency C band radiometer has been added to this system. This operates between 4 and 8 GHz and has a nominal field of view of 18^o. Like the other instruments, this is a single polarization radiometer.

In addition to the microwave radiometers, several other supporting instruments are also mounted on the truck platform. A small portable thermal infrared radiometer by Everest Interscience (Model 110) is used to estimate the surface temperature by measuring thermal emission in the 8-14 μm wavelength range. Target location for the microwave radiometers is achieved with a color video camera installed on the platform between the two antennas. A portable generator on the truck provides electrical power at remote sites. ***Figure 11*** shows the truck with the SLMR installed.

System operation and control is maintained by a personal computer. The software monitors the thermal status of the radiometers and attempts to maintain thermal equilibrium of the defined goal temperature through the distributed heater network. Data collection can be either operator controlled or automatic. The former is used in circumstances where the boom is moved from one target to another or the effect of specific changes are to be observed. In the automatic mode, the system can be set to make observations at specified intervals for extended periods. Due to the low data rates, high temporal frequency is possible.

The main purpose of the truck radiometers is to provide continuous 24-hr brightness temperature measurements to complement the once-a-day aircraft microwave data. The radiometers would be deployed at a representative site. Flux station and other insitu measurements would be made simultaneously providing a high temporal resolution data set for energy and water balance modelling.

The acquisition of SLMR data on a continuous basis during the one month field experiment will provide a context for interpreting any potential temporal variations occurring due to the duration of the day's aircraft mapping flight or ground sampling activities, and will also produce a continuous record for filling in data gaps due to aircraft down time (i.e. weather). In addition, the temporal nature of the SLMR data will permit diurnal effects in the microwave/soil moisture relationship to be calibrated. The resulting data base which combines coverage (aircraft mapping) with high temporal resolution (ground based radiometers) along with supporting meteorological and other insitu observations will be unique, and should have significant impact on the study of surface hydrology and land/atmosphere interactions at different scales.

Deployment of the truck will involve the consideration of several scientific and logistic factors:

1. Side by side grass and winter wheat fields
2. Representativeness of conditions
3. Ancillary observations
4. AC power availability
5. Security
6. Access roads and stability of deployment site
7. Impact of truck operations on pre-existing site operations

At the present time, the truck will be deployed at the Central Facility. A possible backup (in case there are RFI issues) is the ARS lab at Chickasha, OK. If time permits, the truck might be sent to several key sites for a short series of observations.

3. VEGETATION AND LAND COVER

Vegetation data is needed in deriving soil moisture from the microwave observations at a 1 km scale. The basic strategy that will be used involves three components. First, vegetation characteristics will be measured at various locations on the ground that represent an appropriate range of conditions. Then, satellite observations will be used to perform a land classification. On location surveys will be used as part of this supervised approach. This classification will be linked to the ground observations of parameters and used to predict values for each pixel. Classification would be done using TM data resulting in a 30 m data base. However, because the availability of TM data is never certain a plan will be developed that uses both TM and AVHRR.

3.1. Vegetation Sampling

3.1.1. Sampling Plan

Possible stratified random sampling allocation of resources (historic Landsat TM images will be used to locate the sites). The intended allocation is shown in Table 6.

Table 6. Proposed Distribution of Vegetation Sampling Sites

Location	Prairie (30%)	Pasture (50%)	Wheat (10%)	Crops (10%)	Total
Little Washita (1/3)	6	10	2	2	20
El Reno (1/6)	3	5	1	1	10
ARM/CART (1/6)	3	5	1	1	10
Other (1/3)	6	10	2	2	20
Total Sites	18	30	6	6	60

For logistics, all sites used for gravimetric and profile soil moisture sampling will be used for vegetation measurements. However, additional sites will be required. Some considerations in selection include:

1. Minimum field size: 300 m by 300 m (approx 20 acres).
2. Three individual samples per site (separated by at least 100 m and at least 100 m from edge)
3. Each sample from 0.5 m^2 area (0.71 m by 0.71 m)

3.1.2. Resource Requirements

For each of the 60 sites there will be 3 replications (180 samples). An attempt will be made to complete sampling cycle within 2 weeks in order to revisit and resample sites with actively growing vegetation. Teams will consist of one experienced researcher and one assistant each. Each team can collect data and samples from 3 sites/day or 9 samples/day. Three teams will be involved.

Each team will a GPS receiver (1-5 meter accuracy), Plant Canopy Analyzer LAI-2000 (for indirect LAI), Accu-PAR (for fraction absorbed PAR), 35-mm camera and film (for % cover and documentation), electronic balance (for fresh weights in the field), clippers, sampling frame, bags, markers, measuring tapes, labels, etc.

In addition drying facilities for the samples are required. Large capacity dryers for plant samples are available at Chickasha and El Reno. Plant samples in paper bags require 5- 7 days to dry at 70-80^{o}C. If samples average 1 ft3 each, then 180 ft3 dryer space will be required.

3.2. Land Cover Classification

Plans call for the generation of a land cover map for the entire study region. The planned base for this is TM data acquired during the experiment time frame. Classification will be enhanced using supervised techniques based upon field surveys of vegetation/cover conditions conducted prior to and during the experiment.

To date TM scenes have been acquired to assist in various aspects of the planning process and to develop information for the classifier and field survey program.

TM scenes (Path/Row) 28/34, 28/35 and 28/36
Four dates for each scene (April 4, 1991; July 9, 1991; August 26, 1991;
September 11, 1991

Classification will focus on the aircraft mapping area. It is anticipated that TM scenes for 1997 study would be from the same path/rows. Up to three dates, three scenes could be acquired. Scheduled overpasses for scene 28/34 (Path/Row) are;

April 21
May 6, 22
June 7, 23
July 9, 25
August 7, 23

NDVI images derived from the July 9, 1991 TM data are presented in ***Figure 12*** (Little Washita area), ***Figure 13***, El Reno Area, and ***Figure 14***, (Central Facility)

3.3. CASI Aircraft Based Multispectral Data Collection

The CASI imaging spectrometer, a commercial sensor manufactured by ITRES Research Ltd., has undergone extensive evaluation in remote sensing projects around the world. The instrument that will be used in this experiment was acquired under NSERC support, is a commercial unit with some custom features to enhance its utility for research purposes

In the CASI optical design (Anger et al. 1990) a reflection grating provides spectral dispersion of the incoming optical signal over a spectral range of 403 NM to 947 NM (for CASI302) with a spatial resolution of 512 pixels across the 37.9 degree field of view (FOV). Ground resolution ranges from one to ten meters depending on the aircraft altitude. The spectral resolution is nominally 2.5 NM FWHM (full width, half maximum), with 288 spectral channels centered at 1.8 NM intervals. The CCD sensor is read out and digitized to 12 bits by a programmable electronics system which is controlled by an internal single-board computer. Data are recorded on dual built-in digital 8500 Exabyte tape recorder which uses 8 mm cassettes. This low cost, standardized, data storage medium greatly facilitates post processing of the data. Each tape can store up to 2.5 gigabytes of data or depending on the frame rate, up to one hour of imagery. Representative values for the frame rate under typical conditions is 60 frames (lines) /sec for six spectral bands and 37 frames /sec for 16 spectral bands.

Because of the high data rate of the CASI sensor under normal operating conditions various user-selectable operating modes are employed in the CASI system. Each mode maximizes the information content while keeping the data rate at a manageable level.

In the Spatial mode, imagery is obtained at full spatial resolution of 512 spatial pixels across the full swath. Band centre wavelength and bandwidth are operator programmable for up to 18 bands.

In the Spectral mode, imagery is generated at a full spectral resolution of 288 channels for normally up to 39 look directions across the full swath. Look direction spacing and centre location are user specified to sample the array. This sampling normally produces an image rake or comb. A single channel full spatial scene recovery channel can be selected to aid in scene orientation when viewing the imagery.

In HyperSpectral mode imagery is generated by decimating the 288 channels by any integral value that is evenly divisible into 288 i.e. (2, 3, 4, 6, 9 ...). The number of look directions is increased. If a value of 4 is selected, for example, 72 spectral channels with nominal bandwidth of 8 nm are generated in 405 looks. Contact, Lawrence Gray (gray@isl.ists.ca) for further information regarding this or any other aspect of CASI operations.

The CASI data tapes are calibrated to radiance at ISTS. After recovery of the data from the tapes standard processes are applied which compensate for electronic offset and scattered light and frame shift smear within the system. A dark offset correction is then applied. Radiometric calibration of the imagery is undertaken based on calibrations undertaken at ISL at ISTS using software written by EOL staff at ISTS.

The ISTS CASI is also equipped with a roll and pitch correction system. A vertical gyro provides real time pitch & roll aircraft attitude data which is integrated within the CASI data stream written to tape. GPS data from a Novatel receiver is also integrated within the data stream written to tape. A GPS base station is also operated to provide differential correction of the airborne data. This information is used in the postprocessing of the data to produce geo-referenced images.

As a custom feature, the CASI sensor is equipped with a dual optical fibre input fixed to the entrance slit of the spectrograph providing the ability to sample as part of the recorded data stream the spectral content the illumination field. Two cosine receptors, one on the aircraft roof and another on the aircraft belly, provide a measure of up welling and down welling irradiance. A zenith sky radiance probe, also mounted in the roof of the aircraft, is usually multiplexed between the up welling irradiance probe with a switch box.

A program of design, evaluation, calibration and improvement of the diffuser performance is underway to assess the ability of our CASI to provide direct measurements of at-sensor reflectance and estimated surface reflectance.

4. SOIL PHYSICAL AND HYDRAULIC PROPERTIES

4.1. Introduction

This section of the experiment plan for SGP97 describes supporting work in the area of soil physical and hydraulic property characterization and soil and landscape information resources that will be used by SGP97 scientists in both pre-mission preparation and post-mission analysis. The nature and properties of soil are a controlling element in the distribution of soil moisture and, ultimately, in land surface-atmosphere interaction processes. Knowledge of the physical and hydraulic properties of the soil in the SGP97 study area will facilitate correlation of ground and remotely sensed observations of soil moisture and support extrapolation into unmonitored areas. Ultimately, the labor and expense in collecting ground observations of soil moisture in remote sensing mission support will require heavier reliance on existing soil survey and characterization information. This will be of particular importance as we use satellite platforms with global coverage

4.2. Soils of the Region

The SGP '97 area lies predominantly within the Central Rolling Red Prairies and Central Rolling Red Plains land resource areas of Oklahoma (Gray, 1976). A small part of the total experimental area is contained in the Cross Timbers and Bluestem Hills land resource areas. The Central Rolling Red Prairies and Plains areas are smooth to rolling land which are underlain by dominantly red sedimentary strata. Stream gradients are gentle and relief averages only 30 m in smoother portions, with some local relief being greater, particularly in the more rugged southwestern portion of the area. Annual rainfall ranges from 35 inches in the east (Red Prairies) to about 28 inches in the west (Red Plains). Soils in the region are dominantly Mollisols (grassland soils) which reflect slow leaching (low precipitation - subhumid to semiarid climate) with relatively large annual additions of organic matter.

4.3. Soil Survey Resources

4.3.1. SSURGO

The NRCS has not yet created certified digital SSURGO (Soil Geographic Database) products for counties in the SGP97 study area. The detailed county-level soil survey maps for the three counties (Grady, Caddo, and Commanche) that contain the Little Washita River watershed have been digitized independently by the USDA-ARS. These data will be available from the USDA-ARS Grazinglands Research Center in El Reno, OK

4.3.2. STATSGO

A multi-layer soil characteristics data set for the conterminous United States (CONUS-SOIL) that specifically addresses the need for soil physical and hydraulic property information over large areas has been developed at Penn State's Earth System Science Center (ESSC). The State Soil Geographic Database (STATSGO) developed by the United States Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS) served as the starting point for CONUS-SOIL. Geographic information system (GIS) and Perl computer programming language tools were used to create map coverages of soil properties including: soil texture and rock fragment classes, depth-to-bedrock, bulk density, porosity, rock fragment volume, particle-size (sand, silt, and clay) fractions, available water capacity, and hydrologic soil group. Complete documentation of the elements of the data set, as well as the original STATSGO data, and the procedures used to generate each of the elements of CONUS-SOIL are described on a WWW server at **http://eoswww.essc.psu.edu/soils.html**. A subset of the full 48-state CONUS-SOIL is located at: **http://www.essc.psu.edu/ESSC_DB/PROJ_REL_DB/sgp.html**

4.3.3. MIADS

The Map Information Assembly and Display System (MIADS) was developed by the Oklahoma state office of the NRCS in 1981. MIADS is a 200 m (4 ha.) digital raster data set in a UTM map projection. It is based on previously published detailed county-level soil survey maps and was developed with adherence to NRCS standards. The data were originally captured as a series of county map files and are available from the Oklahoma NRCS office in ASCII file format. The Biosystems and Agricultural Engineering Department at Oklahoma State University developed a statewide data set by merging the 77 county map files. For this map coverage, the soil attributes database and the corresponding spatial data base were joined in ARC/INFO. The resulting data format and structure is quite similar to the STATSGO and CONUS-SOIL products mentioned previously. Further information on this statewide coverage is available from Gabriel Senay, Postdoctoral Fellow at Oklahoma State University, Stillwater, OK (e-mail: gsenay@agen.okstate.edu).

4.4. Soil Characterization Data

A concerted effort including literature review, and contacting scientists at the universities and federal and state laboratories will be made to locate water retention, hydraulic conductivity and associated physical soil property data on Oklahoma soils. The data will be catalogued and reformatted into a consistent format and made available to SGP97 collaborators.

4.4.1. NRCS

The NRCS National Soil Survey Center (NSSC), through its Soil Survey Laboratory (SSL) maintains analytical data for more than 20,000 pedons of U.S. soils. Standard morphological pedon descriptions are available for about 15,000 of these pedons. This information includes physical, chemical, and mineralogical data on samples taken in support of the soil survey activities of the NRCS. Although soil hydraulic properties are rarely found within this database, the information that is available on other aspects of soil physical properties may be of relevance for soil moisture modeling research. The relevant pedons for the SGP97 study area will be extracted from this database and the tabular data made available to SGP97 researchers via the WWW.

4.4.2. Oklahoma State Mesonet

Eleven Oklahoma Mesonet sites are within the SGP97 study area or very close to its boundaries. Six of these sites (Acme, Apache, El Reno, Kingfisher, Marshall, and Blackwell) are equipped with soil moisture sensors -- automated heat-dissipation sensors at four depths, and a single TDR probe for periodic monitoring of five soil layers. At the time of sensor installation, soil samples were collected from each of the four depths (5, 25, 60, and 75 cm). A particle size analysis has been conducted for each sample according to ASTM D422-63, and the soil textural classification has been determined.

4.4.3. ARS Little Washita (expected 5/1/97)

4.4.4. Sampling of Soil Physical and Hydraulic Properties

Soil moisture content in the shallow subsurface can most often be described as a variably-saturated phenomenon governed by mass and energy balance. Driving forces for this include (transient) precipitation, antecedent soil moisture content (soil factor), overland runoff (soil and landscape factors), downward infiltration (soil factor), upward exfiltration or evapotranspiration (vegetation factor), soil water retention, and hydraulic conductivity properties. In most soils the constitutive relationships between soil moisture content and soil hydraulic or soil matric potential are nonlinear in nature and thus complicate the transient flow problems. This warrants site-specific measurement of soil hydraulic properties to correlate and extrapolate the transient soil moisture information to deeper depths. This information will be valuable for testing soil moisture data from other sources as well as for modeling variably-saturated flow from shallow surface horizons to deeper soil profile and groundwater aquifers for global water balance.

4.4.4.1. Sites

Site selection will be based primarily on whether there are profile soil moisture measurements at a site, ease of access, and representativeness of the site. Potential sites have been indicated in Table 5.

4.4.4.2. Sampling

4.4.4.2.1. Core Extraction

Soil cores at different depths will be collected from representative (soil, slope, and vegetation) sites using thematic polygons generated via GIS overlay. Nested grids encompassing two or more adjacent quarter sections of higher variability will be used for this purpose. At least two samples (replicates) will be collected for different combinations of soil, topography, and vegetation. Moreover, sampling will be repeated at nearby locations at least two times (e.g., before and after harvest of crop) during the SGP-97 experiment for estimating any temporal variability of soil hydraulic properties. These soil cores will be used for soil water retention, hydraulic conductivity, and texture analysis in the laboratory.

4.4.4.2.2. Surface Characterization

Alabama A & M University will also analyze soil samples for their hydraulic characteristics at the sites of the HSCaRS soil profile stations (6 sites at 5 depths). Soil profiles will be described and sampled for texture, hydraulic conductivity, bulk density and water retention characteristics. A representative grass and winter wheat field in the Little Washita basin will also be sampled (up to 50 samples per field) for surface hydraulic properties. They will use a 3 inch diameter coring tool and aluminum rings. Additional sampling is possible if support is provided for rings and laboratory labor.

4.4.4.3. Laboratory Analysis

The U.S. Salinity Lab will determine the soil water retention and hydraulic conductivity functions for up to 100 soil cores. Approximately 5 different depths based on soil stratigraphic information at 20 different sites will be selected at Little Washita, El Reno, and Lamont. Soil cores (e.g., using brass cylinders of 2 1/4" O.D. and soil core sampler cat. no. 200, Soil Moisture Equipment, Santa Barbara, CA) collected from different selected sites and depths will be preserved and transported to the U.S. Salinity Lab, Riverside, CA. Soil water characteristics (draining curve) of these cores at several soil water suctions between 0 - 15 bar will be measured using pressure cells and pressure plat extractors following a multi-step outflow experiment. All these experiments will be conducted in constant temperature chambers to minimize any temperature effect on soil hydraulic properties. Subsequently these data will be used to determine unsaturated hydraulic conductivity functions adopting predicative approaches (Mualem 1986) by means of the RETC computer code (van Genuchten et al. 1991).

4.5. Topographic Data

4.5.1. USGS 1 km and 3-arc second

Digital elevation information for the SGP97 study area is available in three grid resolutions: 1-km, 3-arc second (~100 m), and 30 m. The 1-km and 3-arc second data were obtained from the USGS and are available at the Penn State SGP WWW site: http://www.essc.psu.edu/ESSC_DB/PROJ_REL_DB/sgp.html.

4.5.2. ARS Little Washita 30 m (expected 5/1/97)

The 30 m (7.5 minute) USGS DEM's for the Little Washita River Basin are available from the USDA-ARS Grazinglands Research Center in El Reno, OK. The other intensive study sites in the SGP97 study area (El Reno and the ARM/CART sites) do not have 30 m DEM data available.

5. PLANETARY BOUNDARY LAYER OBSERVATIONS (next update 4/30/97)

The boundary layer component of SGP97 is configured to primarily evaluate the influence of soil moisture on the local surface energy budget and the influence of mesoscale variability in the surface energy budget on the development of convective boundary layer. To the extent possible, attempts will be made to quantify the water vapor budget of the boundary layer (advection, entrainment, and evapotranspiration) using remotely sensed and in situ data. The instrumentation to be deployed during SGP97 and the data to be collected are described below. The plan is not yet complete particularly in regard to the flight plans of the two flux aircraft; an update is expected on 4/30/97.

5.1. Water vapor profiles

Aboard the Wallops P-3 aircraft together with ESTAR, the NASA Langley Research Center (LaRC) instrument, Lidar Atmospheric Sensing Experiment (LASE), will provide observations of atmospheric water vapor and aerosol profiles, and locations of cloud top along the flight track. The LASE instrument is a compact and highly engineered differential absorption lidar (DIAL) system that has completed its development and validation aboard the high-altitude ER-2 aircraft (Higdon et al., 1994; Browell et al., 1996); the lidar parameters are given in Table 7.

Differential Absorption Lidar (DIAL) is an active remote sensing technique that takes advantage of the absorption of the pulsed laser light along the beam direction to obtain the concentration of the molecular species that causes the selective absorption. In practice, two laser pulses are transmitted near simultaneously one at the peak of the absorption line called the "on-line" and another in the wing of the absorption line called the "off-line". An illustration of the DIAL principle is given in ***Figure 15***. If P_{on} and P_{off} denote power received “on-line” and “off-line”, respectively, the average molecular number density between ranges R_1 and R_2 is calculated using the relation:

$$n = \frac{1}{2\Delta s\,(R_2 - R_1)} \; \frac{P_{on}(R_1)\,P_{off}(R_2)}{P_{on}(R_2)\,P_{off}(R_1)}$$

The advantage of the DIAL method is that it can be used to obtain range-resolved profiles of atmospheric gases with high vertical resolution. In addition to measuring gas concentration profiles, high spatial resolution aerosol backscattering distributions are simultaneously obtained as part of the DIAL measurement using the off-line lidar signals. DIAL offers the advantage of adjusting vertical and/or horizontal resolution by averaging the lidar data that are collected at a very high resolution. With the DIAL method, lidar measurements can be made during day or night and between and above cloudy regions in the atmosphere.

Table 7. LASE H_2O DIAL Parameters	
TRANSMITTER	
ENERGY	150 MJ (ON & OFF)
LINEWIDTH	0.25 PM
REP. RATE	5 HZ
WAVELENGTH	813-818 NM
BEAM DIVERGENCE	0.60 MR
PULSE WIDTH	50 NS
RECEIVER	
AREA (EFFECTIVE)	0.11 M^2
FIELD OF VIEW	1.1 MR
FILTER BANDWIDTH ($\Delta\lambda$FWHM)	0.4 NM (DAY) 1.0 NM (NIGHT)
OPTICAL TRANSMITTANCE (TOTAL)	29% (DAY) 49% (NIGHT)
DETECTOR EFFICIENCY	80% APD (SI)
NOISE EQ. POWER	2.5 X 10^{-14} W/HZ^{12} (AT 1.6 MHZ)
EXCESS NOISE FACTOR (APD)	2.5

In the current mode of operation LASE operates locked to a strong water vapor line and electronically tunes to any spectral position on the absorption line profile. This permits the choice of suitable absorption cross-sections for optimum measurements over a wide range of water vapor concentrations in the atmosphere. In addition, electronic tuning allows the system to rapidly take data over two or three water vapor concentration ranges. This unique method of operation permits rapid and flexible absorption cross-section sampling capability and provides water vapor measurements over the entire troposphere on one aircraft pass. This new method of using two water vapor absorption cross-sections from a single water line (one on the line center and one on the side of the line) was implemented and tested during the LASE validation experiment in September 1995; the intercomparison with a number in situ and remote sensors from the ground and other aircraft demonstrated the accuracy, reliability, and dynamic range of LASE measurements.

The LASE system has been developed as a precursor to a space-based DIAL instrument, and has operated autonomously from the ER-2 aircraft. Several modifications are being made in order to deploy LASE aboard the P-3 aircraft during SGP97; the projected capabilities are listed in Table 8. The projected performance (random error profiles, representing the precision of the water vapor measurement) of LASE aboard P-3 is compared with the LASE capability from the ER-2 in ***Figure 16.***

Table 8. LASE Water Vapor and Aerosol Profiling Capability on P3 (SGP97 Mission)	
WATER VAPOR	
ALTITUDE COVERAGE	GROUND TO NEAR AIRCRAFT
MEASUREMENT CAPABILITY	DAY AND NIGHT
MEASUREMENT RANGE	0.01 G/KG TO 20 G/KG
ACCURACY (MIXING RATIO)	BETTER THAN 10% (OR 0.01 G/KG)
RESOLUTION (NOMINAL)	10 KM (HORIZ),0.3KM (VERTICAL)
AEROSOL BACKSCATTER (815-NM)	
ALTITUDE COVERAGE	GROUND TO NEAR AIRCRAFT
MEASUREMENT CAPABILITY	DAY AND NIGHT
MEASUREMENT RANGE	0.2 TO >100 (AER. SCAT. RATIOS)
PRECISION	BETTER THAN 3% (OR 0.2 S/R)
RESOLUTION	0.2 KM (HORIZ,0.03 KM (VERTICAL)
*LASE DATA WILL BE REDUCED TO RETAIN HIGHEST RESOLUTION POSSIBLE IN THE PBL. ALGORITHMS ARE IN PROGRESS TO EXTEND WATER VAPOR PROFILES TO WITHIN 100M OF GROUND	

.

An upgraded computer system is planned to support on-board LASE monitoring, data processing and analysis; the post-processing will be used to produce analysis products more refined than is possible with the real-time processing. The on-board data display will provide real-time information concerning the development of the convective boundary layer via images of lidar backscatter. These observations can be used to guide the flux aircraft with regard to choice of flight altitudes and the location of interesting mesoscale features.

5.2. Airborne fluxes

Two research aircraft will be deployed for the measurement of eddy fluxes of momentum, latent and sensible heat, and other scalars, along with the measurement of mean thermodynamic variables and various radiative components; one is the Twin Otter from the National Research Council (NRC), Canada, and the other the Long-EZ airplane from the NOAA Atmospheric Turbulence and Diffusion Division (ATDD). The flight plans are in the process being defined, keeping in mind the possible airspace and operational limitations. The basic objective, however, is to make boundary layer measurements at several altitudes across an area with large gradients in soil moisture that are prompted by recent contrasts in either wetting or drying conditions. At this writing, three types of flight operations are being contemplated:

(1) Reciprocal runs at various altitudes from near the surface (100 ft) to on top of the boundary layer (perhaps 5000 ft). These tracks would be approximately 10-30 km in length and would be along a gradient in soil moisture. It is proposed that several such tracks be planned well in advance of the project in cooperation with the FAA. On any given day one or two of these tracks would be activated, the selection being made at the previous evening's briefing based on data from the surface sites and the P-3.

(2) Coordinated flights with the P-3, likely flying long segments of the four primary P-3 tracks. Again, these runs would be flown at several altitudes, perhaps also coordinated with the second flux aircraft (ATDD Long-EZ). It is possible that on these tracks the Twin Otter would not fly below 500 ft.

(3) Intercomparison flights with surface-based systems. There are three areas in the overall operational area that have significant arrays of surface moisture measurements as well as occasional flux-measuring stations (see section 5.3). These intercomparison would consist of low altitude passes (down to 100 ft if possible) on relatively short tracks, perhaps 5 km or less.

5.2.1. NRC Twin Otter

The NRC Twin Otter atmospheric research aircraft is a twin-engine turboprop STOL transport with a gross takeoff weight of 11579 lb. Without the use of a supplementary oxygen system, it has a service ceiling of 10,000 feet and an endurance of about 3.5 hours (depending on installed instrumentation). In its trace gas flux-measuring role, the aircraft is flown at about 105 knots (55 mps) and can operate at altitudes as low as 100 feet. Research flights are usually flown with a crew of four.

Configured for flux measurement, the basic instrumentation aboard the aircraft measures the following:

- the three orthogonal components of atmospheric motion.
- the vertical fluxes of sensible and latent heat, momentum, turbulent kinetic energy, CO_2 and ozone.
- concentrations of CO_2, H_2O and ozone.
- atmospheric state parameters such as pressure, temperature, dew point, and mean winds.
- aircraft position (GPS), motion and attitude (Litton-90 Inertial Reference System), pressure height, and height above ground (radio-altimeter, laser altimeter).
- radiometric surface temperature, incident and reflected solar radiation, net radiation, greenness index (NDVI), 4-channel satellite simulator (Landsat or SPOT).
- VHS videotape using under-nose and side-looking cameras with superimposed listing of time, altitude, heading, latitude and longitude.

Data are recorded digitally on DAT tape at a rate of 32 Hz, after anti-alias filtering at 10 Hz, giving an along-track resolution of about 5 meters at the usual flux measuring speed of 50-55 mps. Winds and estimated fluxes are computed in real time by the aircraft's VME-based computer system, with results immediately displayed to the cockpit and cabin crew. This allows the crew to assess the state of the boundary layer, or recognize instrumentation problems, and modify the flight plan as required.

Along with aircraft spares and maintenance equipment, a full data playback facility is transported to the field site, and is usually set up in a meeting room in the crew's hotel. Within a few hours of landing, collaborating scientists can have access to the analyzed data, which includes run-averaged fluxes, analog traces, flight tracks, videotape, tephigrams from soundings, spectra and cospectra of flux contributions. A review of these data allows scientists to compare the measurements with expectations and with data from other sensing platforms, and thus make decisions on the scientific direction of subsequent flights.

After the completion of the field phase of the experiment, the data are re-analyzed, applying adjusted calibrations, and correcting the measured horizontal wind data using a Kalman-filtering technique, which removes small drifts present in velocity measurements from inertial navigation systems. The run-averaged results and all 32-Hz data (approximately 160 variables) are archived on optical disk. At the request of collaborating scientists, these files can be accessed at a later date to strip off time histories of a selection of parameters, which are then electronically transferred by ftp. For this project, run-averaged data could also be archived in the format used in the BOREAS project and already stored at NASA. Finally, about six months after completion of the field experiment, NRC will produce a project report, which will include a description of the instrumentation used, a summary of all the flights, data presentations and preliminary analyses related to the objectives of the experiment. An example of the report from the 1994 BOREAS project is available upon request. More information can also be found at the website **(http://www.cmc.ec.gc.ca/rpn/mermoz).**

5.2.2. ATDD Long-EZ

The Long-EZ flux aircraft, N3R, is an experimental airplane; with its wide body and higher power, it is more capable than the standard Rutan Long-EZ, a two passenger high performance canard airplane. Its aerodynamic characteristics have many advantages for high-fidelity turbulent flux measurement. The small, laminar-flow airframe has an equivalent flat plate drag area of 0.2 m^2, minimizing flow distortion at the nose for high-fidelity measurements of winds, temperature and trace species. The pusher configuration leaves the nose free of propeller-induced disturbance, engine vibration, and exhaust. The canard design resists stalling and has excellent pitch stability in turbulent conditions. This, combined with its low wing loading, allows for safe low-speed (50 m s^{-1}), low-altitude (10 m) flux measurement. For enhanced safety, the Long-EZ is equipped with a ballistically-deployed safety parachute (deployment requires 0.9 s).

The Long-EZ has an empty mass of 430 kg and a maximum gross takeoff mass of 800 kg. Endurance significantly exceeds 10 hours, although pilot fatigue precludes routine 10-hour missions. Typical operations include two 4-hr or three 3-hr missions. The small size allows operation from relatively small airports, though requiring at least 1000m of paved runway.

The airborne flux instrumentation, and the data system with its associated software were specifically designed and built by ATDD (Crawford *et al.*, 1990). Wind velocity and temperature fluctuations are measured with ATDD's turbulence probe (Crawford and Dobosy, 1992). The probe is mounted five chord lengths ahead of the wings, where flow distortion is small (Crawford *et al.*, 1996). It carries pressure, temperature and acceleration sensors in a nine-hole pressure-sphere gust probe of ATDD design. This sensor suite is specifically designed for eddy-flux measurement at the higher frequencies required for low altitude flight. A thermistor in the central pressure port provides simultaneous temperature measurement, at a location symmetrical with respect to the flow, for accurate determination of true air speed and heat flux. Water-vapor and CO_2 fluctuations are measured with an open-path, infrared gas absorption (IRGA) analyzer, developed at ATDD (Auble and Meyers, 1992). This sensor responds to frequencies up to 40 Hz, has low noise and high sensitivity (for CO_2, 20 mg m^{-3} v^{-1}). The sensor is rugged and experiences little drift.

A unique difference in the Long-EZ instrument system is its pioneering use of a mix of differentially-corrected GPS and integrated acceleration measurements to determine position, velocity, and platform attitude. Differential correction of GPS involves determining the position or velocity as a relative quantity, the difference between values at two receivers. Many GPS errors are common to all receivers in a given area and are canceled when the measurements from two separate receivers are subtracted. The receivers we use report position, velocity and attitude ten times per second. To obtain this information at higher frequencies we integrate acceleration measurements. By adding filtered signals (high pass for integrated accelerations, and low pass for GPS) information on position, velocity, and attitude of the Long-EZ can be obtained over the same range obtainable from a high-quality inertial navigation system (INS).

The data stream is dominated by high-frequency analog signals from the accelerometers, pressure sensors and the like. Analog signals are first electronically conditioned by 30-Hz lowpass Butterworth anti-aliasing filters. The conditioned signals are then sampled and digitized at 250 Hz. The 250-Hz data are digitally filtered and sub-sampled to 50 Hz. Although several other data frequencies are being written to disk, all are synchronized to a single clock frequency. Spectra and cospectra data analysis show that the 50-Hz flux data rate is adequate for measuring fluxes at the Long-EZ flight speed and altitude. The final, meteorologically relevant quantities from Long-EZ are listed in Tables 9 and 10.

Table 9. Long-EZ Measurements, Data Provided Fifty Per Second

Datum	Units	Measured/Derived
Eastward wind U	m s^{-1}	Derived
Northward wind V	m s^{-1}	Derived
Upward wind W	m s^{-1}	Derived
Air Temperature (probe)	K	Adjusted for dynamic pressure
Air Temperature (hatch)	K	Adjusted for dynamic pressure
H_2O mixing ratio	g(H2O) kg^{-1} (dry air)	Converted from vapor density (IRGA)
CO_2	mg(CO_2) kg^{-1} (dry air)	Converted from gas density (IRGA)

Ambient pressure	mb	Corrected for airspeed and angle of attack/slideslip
Laser Altitude	m	Measured
rW	kg m^{-2} s^{-1}	Dry-air density times W

Table 10. Long-EZ Measurements, Data Provided Once per Second		
Datum	Units	Derived/Measured
Latitude	Deg	Derived (GPS)
Longitude	Deg	Derived (GPS)
Altitude	m	Derived (GPS)
Exotech radiometer four channels	Filters to match TM, SPOT, MSS	Measured
PARdownwelling	mEinstein m^{-2} s^{-1}	Measured
PARupwelling	mEinstein m^{-2} s^{-1}	Measured
Net Radiation	W m^{-2}	Measured
Surface Temperature	C	Derived (Infrared)
Radar Altitude	m	Measured
CO_2 mixing ratio	mMole $Mole^{-1}$	Measured (LiCor)
H_2O mixing ratio	mMole $Mole^{-1}$	Measured (LiCor)
Ground Speed	m s^{-1}	Derived

5.3. Surface Flux Measurements

In addition to the ARM surface flux stations within the SGP study area, there will be a group of investigators collecting surface flux and ancillary meteorological data during the SGP intensive field campaign. These are summarized below:

NASA-GSFC/Univ of Arizona

The Univ of Arizona Eddy Correlation system measures the 3D wind vector with a weather resistant Solent sonic anemometer, and concentrations of CO2 and H2O using a Li-Cor 6262 infrared gas analyzer at 20 Hz. All the raw data is saved, and processed at a later time on a PC (but a real-time first guess is possible). Supporting measurements are standard met variables measured with a Campbell weather station: wind speed and direction, relative humidity, air temperature, solar and net radiation, soil temperature, soil heat flux, and rainfall. Plans for deployment are still TBD. The goal is to help validate the ARM EC and Bowen Ratio measurements.

USDA-ARS

The USDA-ARS plans to conduct measurements at three sites within the El Reno facility. The sites will be representative of the three main vegetation cover types: winter wheat, Bermuda grass and natural rangeland/prairie. At each site a Campbell 3D sonic anemometer along with a 1D KH2O for measuring sensible and latent heat fluxes will be deployed. Ancillary measurements will include soil temperature, soil heat flux and meteorological observations: wind speed and direction, air temperature, relative humidity, and net and solar radiation. There are also plans to co-locate a Campbell Scientific Bowen ratio system using the Li-Cor 6262 CO2/H2O gas analyzers at two of the sites. In addition, there are plans to install on a more permanent basis three SHAWMS (Soil Heat And Water Measurement Systems) nearby the flux measurement systems. These systems measure soil heat flux, soil temperatures, soil thermal conductivity and moisture in the root zone (approximately the first 1 m of the soil profile). At the three sites radiometric surface temperatures will be collected on a continuous basis using Everest 4000's.

Univ of Wisconsin

A major focus of this group will be to conduct comparisons between a "roving" eddy correlation unit (consisting of a 3D sonic and 1D KH2O) and the different instrumentation running at the various flux stations during the SGP study period. Part of this “roving” system, will be a newly purchased Kipp & Zonen CNR-1 net radiometer to compare with net radiometer measurements being made by other net radiometer type(s). This project will help determine which flux stations may be having problems or at the very least showing large discrepancies with the “roving” system. It will also provide a means for reducing variation in net radiation observations caused by differences in net radiometer types/calibrations. They are also planning the installation of infrared radiometers at as many of the flux sites as possible for recording surface temperature on a continuous basis.

JPL

Main interest is to collect surface flux data during aircraft thermal infrared observations and compare eddy correlation measurements using different instrument types with ground-based thermal infrared observations. Instruments include; a Campbell Scientific 3-D sonic and a 1-D sonic system, a couple of KH20 for EC humidity measurements, and about 6-8 fine wire thermocouples that could be used for sensible heat flux estimation via the variance method, a TDR for soil moisture measurements, and about 60 or more soil thermocouples. Will also be able to bring along at least one Everest IR radiometer, about 5-10 CSI data loggers, a profile system with anemometers, thermocouples, and humidity sensors that can be used for estimating surface roughness as well as to compare with the eddy correlation and Bowen ratio systems. Have not decided on a location for his surface flux and ancillary meteorological measurements.

Georgia Tech

Campbell Scientific Bowen ratio system and will be siting the instrumentation with the sounding location in the Little Washita Watershed. The exact location is unknown, but plans are to locate on a pasture site. Measurements include incoming solar radiation, net radiation, ground heat flux and soil temperature, wind speed and direction, surface pressure, air temperature, and relative humidity .

NOAA/AATD

This group has been collecting energy and CO2 flux data on a continuous basis at a rangeland site in the Little Washita. The flux instrumentation includes a 3-D sonic (Gill instruments, model R2) and an ATDD open path H2O/CO2 gas analyzer. Ancillary measurements include net and solar radiation, incoming and reflected PAR, soil temperatures (at 6 levels), ground heat flux, precipitation, surface wetness, surface temperature, air temperature and relative humidity, atmospheric pressure, and soil moisture.

5.4. Atmospheric Soundings

In addition to the ARM IOP sounding schedule of 8 times per day at the CF and 4 BF's (see Section 7), a tethersonde system will be deployed from the Little Washita with emphasis on the morning hours. (A radiosonde system to the southwest corner of the SGP domain is pending.)

6. SATELLITE DATA ACQUISITIONS

6.1. Landsat Thematic Mapper (TM)

TM scenes have been acquired for four dates from previous years to assist in the site selection and vegetation studies. We will attempt to acquire two dates of coverage during the experiment period in 1997.

6.2. Priroda

Priroda is a module on the Russian MIR spacecraft. It is in a circular orbit at an altitude of 360 km over the Earth surface and inclination of 51.7^{o}. Priroda includes a variety of unique remote sensing instruments, especially passive microwave. Major features are described in Table 11. Data are being requested for all possible coverages, however, there are potential conflicts that may limit coverage. In addition, data turnaround is uncertain at this time since there have been no data sets provided to date.

Table 11. Priroda Sensors

Sensor	Wavelength	Beamwidth (Degrees)	Spatial Resolution (km)	Swath (km)
Passive Microwave (IKAR)				
IKAR-N (Nadir)	0.3, 0.8, 1.35, 2.25, 6 cm	9	60	60
IKAR-D (Scanning)	0.3, 0.8, 1.35, 4 cm	1, 1.5, 2, 6	5, 8, 15, 50	400
IKAR-P (Pushbroom)	2.25 and 6 cm)	6,12	75	750
Radar (Travers)				
SAR	9.2 and 23 cm	1x4, 2.5 x 4	0.15	100
Visible and Infrared				
ISTOK	3.6 -16 μm	64 channel	1 x 6	6
MOS-OBZOR	0.415 -1.03 μm	17	0.6	80
MSU-SK	0.5 -12.5 μm	5	120 m	350

Table 11. Priroda Sensors				
Sensor	Wavelength	Beamwidth (Degrees)	Spatial Resolution (km)	Swath (km)
MSU-E	0.5 - 0.9 μm	3	35 m	27

6.3. Advanced Very High Resolution Radiometer (AVHRR)

This is a TIROS-N series satellite designed to operate in a near-polar, sun-synchronous orbit. There may be two satellites in this series that are in orbit during the experiments. The NOAA-14 satellite in the ascending node (northbound Equator crossing) has a daytime pass of approximately 1340 hours local solar time. The NOAA-12 satellite in the descending node (southbound Equator crossing) has a daytime pass of approximately 0730 hours. Sensor characteristics are described below.

Sensor Band Characteristics:

Band 1	0.58 - 0.68 (micrometers)
2	0.725 - 1.10
3	3.55 - 3.93
4	10.3 - 11.3
5	11.5 - 12.5

Sensor Spatial Resolution: 1.1 Km (all bands) at Nadir pass
Temporal Resolution: 14.1 orbits/day
Swath: 2048 pixels wide
Scan Angle Range: -55.4 to +55.4 degrees

6.4. Radar Satellites

Data from three different synthetic aperture radar (SAR) satellites will be acquired, pending negotiations. These are Radarsat, ERS, and JERS.

Radarsat is operated by the Canadian Space Agency. It is a C band SAR with HH polarization. It is in a sun-synchronous orbit at an altitude of 798 kilometers above the Earth, at an inclination of 98.6 degrees to the equatorial plane. The sun-synchronous orbit also means that the satellite overpasses are always at the same local mean time. As opposed to the other radar satellites, Radarsat can provide a variety of beam selections. It has the ability to shape and steer its beam from an incidence angle of less than 20 degrees to more than 50 degrees, in swaths of 35 to 500 kilometers, using resolutions ranging from 10 to 100 meters. Up to 20 scenes will be acquired (various dates, configurations and coverage areas), however, these data are subject to distribution limitations due to Radarsat regulations.

The ERS (European Remote Sensing Satellite) is a global environmental monitoring satellite that has a fixed incidence angle of 23°. It is a C-band synthetic aperture radar (SAR) operating at VV polarization. As much coverage as possible will be requested for the experiment period. These data will have restrictions on distribution.

JERS-1 (the Japanese Environmental Satellite) is an L-band HH SAR operating at an incidence angle of 30°. At least one scene will be requested and distribution may be restricted.

6.5. Special Sensor Microwave Imager (SSM/I)

The (SSM/I) has been a part of the Defense Meteorological Satellite Program (DMSP) since July, 1987. It is a multifrequency imaging radiometer that utilizes conical scanning at an incidence angle of 50°. It operates in a circular sun-synchronous near polar orbit at an altitude of 833 km and an inclination of 98.8°. Basic parameters for the sensors are listed in Table 12.

Table 12. SSM/I Sensors

Frequency (GHz)	Polarizations	Resolution (km) (along and cross track)
19.35	V and H	69 x 43
22.235	V	60 x 40
37.0	V and H	37 x 28
85.5	V and H	15 x 13

The total swath is 1400 km. We will attempt to acquire data from all passes and satellites during the study period. These data will be resampled to a standard grid.

6.6. GOES (expected 5/1/97)

7. DOE ARM CART

The Department of Energy (DOE) Atmospheric Radiation Measurement Program (ARM) operates a tremendous number and types of instruments. The Southern Great Plains is one of the Cloud and Radiation Testbeds (CART). Here a simplification of the extensive materials prepared by the ARM CART **(URL www.arm.gov/docs/sites/sgp/sgp.html**). The site layout is based upon a heavily instrumented central facility (CF) surrounded by 22 extended facilities (fewer instruments) (EF), 4 boundary facilities (BF), and 3 intermediate facilities (IF). Figure 1 includes the locations of all facilities.

Instrumentation at the CF is listed in Table 13. EF sites include the SIROS, SMOS, EBBR or ECOR, and SWATS. IF facilities include BBSS, MWR, and a 404 MHZ Wind Profilers. Each IF has a 915 MHZ Wind Profiler.

The schedule for BBSS launches is as follows:

Routine Schedule	CF-0600, 1200, 1500, 1800, 2100 UMT
	BF-1800 UMT (1200 local)
IOP Schedule	CF-0300, 0600, 0900, 1200, 1500, 1800, 2100, 2400
	BF-0300, 0600, 0900, 1200, 1500, 1800, 2100, 2400

The Central facility includes two EF sites, one range and the other winter wheat. Therefore, many of the instruments are replicated for each cover type (radiometric observations, wind, temperature and humidity sounding systems, energy balance, surface meteorology, and soil moisture and temperature profile). There are currently 22 EF sites designed to primarily to monitor surface and moisture (energy balance, surface meteorology, and soil moisture and temperature profile).

Table 13. ARM CART Central Facility Observations		
Radiometric Observations	Atmospherically Emitted Radiance Interferometer **(AERI)**	
	Solar Radiance Transmission Interferometer **(SORTI)**	
	Broad Band Solar Radiation Network **(BSRN)**	Pyranometers
		Pyrgeometer
		Pyrheliometer
		Multifilter Rotating Shadow Band Radiometer (MFRSR)
	Solar and Infrared Radiation Observing System (**SIROS**)	Pyranometers up and downwelling
		Pyrgeometer up and downwelling
		Pyrheliometer
		Multifilter Rotating Shadow Band Radiometer (MFRSR)
	UV-B PAR, Multifilter Radiometer **(MFR)**	
Wind, Temperature and Humidity Sounding Systems	Balloon Borne Sounding System (**BBSS**)	Pressure
		Temperature
		Relative Humidity
		Wind Speed
		Wind Direction
	915MHz Profiler with RASS	
	50 MHZ Profiler with RASS	
	Microwave Radiometer	
	Raman Lidar	
	Infrared Thermometer	
Cloud Observations	Whole Sky Imager	
	Belfort Laser Ceilometer	
	Micropulse Lidar	
	Millimeter Cloud Radar	
Other	Temp and Humidity at 25 and 60 m tower	
	Energy Balance Bowen Ratio (**EBBR**)	Air Temperature at Two Heights
		Relative Humidity at Two Heights
		Net Radiation at 2 m
		Near Surface Soil Moisture (2.5 cm)
		Near Surface Soil Temperature (0-5 cm)

Table 13. ARM CART Central Facility Observations		
		Near Surface Soil Heat Flux (5 cm)
		Atmospheric Barometric Pressure
		Wind Direction at 2.5 m
		Wind Speed at 2.5 m
	Eddy Correlation (**ECOR**)	Air Temperature
		Relative Humidity
		Wind Direction
		Wind Speed
	Surface Meteorological Observation Station (**SMOS**)	Air Temperature at 2 m
		Relative Humidity at 2 m
		Atmospheric Barometric Pressure
		Wind Direction at 10 m
		Wind Speed at 10 m
		Precipitation
		Snow Depth
	Soil Water and Temperature System (**SWATS**	Soil Moisture (5, 15, 25, 35, 45, 85, 125, and 175 cm depths)
		Soil Temperature (5, 15, 25, 35, 45, 85, 125, and 175 cm depths)

8. GEOLOCATION OF GROUND SITES

A list of all ground locations of interest to any investigator will be compiled. All sites will be located using a government usage GPS instrument by a single team. These locations include;

Corners of all sites used for surface soil moisture
Profile soil moisture stations
Mesonet locations in the study region
ARM facilities in the study region
Flux stations

9. OPERATIONS

9.1. Experiment Management

<table>
<tr><td colspan="9">Table 14. Experiment Operations Management</td></tr>
<tr><td colspan="9">Mission Manager (T. Jackson)</td></tr>
<tr><td colspan="3">Mission Scientist Land (T. Jackson)</td><td colspan="3">Mission Scientist Atmosphere (L. Mahrt)</td><td colspan="3">Site Operation</td></tr>
<tr><td colspan="3">Data Collection Coordinators</td><td colspan="3">Data Collection Coordinators</td><td rowspan="2">Chickasha</td><td rowspan="2">El Reno</td><td rowspan="2">Central
Facility</td></tr>
<tr><td>Remote Sensing</td><td>Soil
Moisture</td><td>Site Characterization</td><td rowspan="2">Aircraft
(L. Mahrt)</td><td rowspan="2">Flux
Stations
(B. Kustas)</td><td rowspan="2">Soundings
(R. Peppler/
C. Peters-Lidard)</td></tr>
<tr><td>Aircraft
(T. Jackson)

Truck
(P. O'Neill)</td><td>Surface
(T. Jackson)

Profile
(P. Starks)</td><td>Land Cover
(P. Doriaswamy)

Vegetation
(S. Hollinger)

Bulk Density
(L. McKee)

Soil Properties
(B. Mohanty)</td><td>J. Famiglietti
G. Heathman</td><td>P. Starks
B. Wickel</td><td>P. O'Neill
J. Teske</td></tr>
</table>

9.1.1. Aircraft Coordination and Plans

Table 15. **Aircraft Coordination**

Aircraft	Mission Scientist	Aircraft Manager	Instrument Scientists
NASA P3	T. Jackson	P. Bradfield	ESTAR (D. LeVine)
			LASE (E. Browell)
			C Band (C. Swift)
			SWTIR (C. Swift)
PSRO Piper Navajo Cheiftan	T. Jackson	L. Gray	SLFMR (L. Gray)
			CASI (L. Gray)
DOE Cessna Citation	T. Schmugge	J. Myers	TIMS (J. Myers)
NRC Twin Otter	L. Mahrt/ D. Entekhabi	I. Macpherson	Flux Sensors (I. Macpherson)
			19 GHz Radiometer (A. Walker)
NOAA Long-EZ	L. Mahrt/ D. Entekhabi	T. Crawford	Flux Sensors (R. Dobosy)

9.1.2. Ground Observations and Sampling (expected 5/1/97)

9.2 Safety

9.2.1. Field Hazards

There are a number of potential hazards in doing field work. Common sense can avoid some of these;

Work in teams of two
Carry a phone
Know where you are
Dress correctly; long pants, long sleeves, boots, hat
Use sunscreen and bring fluids

There are other hazards that require a proactive approach to minimize. The following information is provided for general purposes and was extracted from materials at cited web sites. In all cases, if you have an emergency get to a hospital. For minor problems contact the area operations manager.

9.2.1.1. Chiggers

Chiggers are the larvae of mites (about ½ mm in size). Chiggers are most often found in low, damp areas where vegetation is heavy, although some species prefer dry areas. Chiggers can cause intense itching and small reddish welts on the skin.The intense irritation and subsequent scratching may result in secondary infection.

Chiggers attach themselves to the skin, hair follicles or pores by inserting their piercing mouthparts. When chiggers attach to humans, they are not usually noticed for some time. During feeding, they inject a fluid into the skin which dissolves tissue. Chiggers feed by sucking up the liquified tissues.

Itching from chigger bites is usually noticed 4-8 hours after chiggers have attached or have been accidentally removed. The fluid injection causes welts to appear which may last for two weeks. They will also cause a tiny red spot to develop on your skin. As time goes by, the itch will get worse and the red spot will get larger. Some people exhibit an allergic reaction to the injected fluid which results in severe swelling, itching, and fever. People mistakenly believe that chiggers embed themselves in the skin or that the welts contain chiggers. Often scratching at the welt results in secondary infection.

Chiggers prefer to attach on parts of the body where clothing fits tightly or where the flesh is thin, tender, or wrinkled. For this reason, chiggers locate in such areas as the ankles, waistline, knees, or armpits.

Chiggers are easily removed from the skin by taking a hot bath or shower and lathering with soap several times. The bath will kill attached chiggers and others which are not attached. Since symptoms of contact may not appear for several hours, it is not always possible to completely prevent welts caused by chigger bites. Antiseptic should be applied to all welts which do appear. It is important, but hard to remember not to scratch chigger bites. Temporary relief of itching may be achieved with nonprescription local anesthetics available at most drug stores. Studies have shown that meat tenderizer, rubbed into the welt, will alleviate itching, as will calamine lotion. So will antihistamines such as Benadryl.

If you are going into areas suspected of being infested with chiggers, wear protective clothing and use repellents. Repellents should be applied to legs, ankles, cuffs, waist, and sleeves by clothing application or directly to the body as directed by the label. Wear an insect repellent that contains DEET.

(Sources: http://hammock.ifas.ufl.edu/tmp/chiggers.html and http://kidshealth.org/kid/games/chigger.html)

9.2.1.2. Ticks

Ticks are flat, grey or brownish and about an eighth of an inch long. When they are filled with their victim's blood they can grow to be about a quarter of an inch around. If a tick bites you, you won't feel any pain. In fact you probably won't even know it until you find the tick clamped on tightly to your body. There may be some redness around the area, and in the case of a deer tick bite, the kind that carries Lyme Disease, a red "bulls-eye" may develop around the area. This pattern could spread over several inches of your body.

When you find a tick on you body, soak a cotton ball with alcohol and swab the tick. This will make it loosen its grip and fall off. Be patient, and don't try to pull the tick off. If you pull it off and it leaves its mouth-parts in you, you might develop an irritation around these remaining pieces of tick. You can also kill ticks on you by swabbing them with a drop of hot wax (ouch!) or fingernail polish. After you've removed the tick, wash the area with soap and water and swab it with an antiseptic such as iodine.

Ticks are very common outdoors during warm weather. When you are outdoors in fields and in the woods, wear long pants and boots. Also spray yourself before you go out with insect repellent containing DEET.

(Sources: http://kidshealth.org/cgi-bin/print_hit_bold.pl/kid/games/tick.html?ticks#first _hit)

9.2.1.3. Snakes

Everyone will be provided with a snakebite kit which will contain instructions. The following are some emergency procedures

WHAT TO DO IF BITTEN BY A VENOMOUS SNAKE

Allow bite to bleed freely 30 secs.
Use Sawyer Extractor (see below) for 15secs to 1 minute over both fang tracks
Cleanse and/or disinfect bite area throughly if possible
Apply hard direct pressure over bite using a 4 x 4 gauze pad folded in half x 2
Soak gauze pad in Betadine(tm) solution if available if not allergic
Strap gauze pad tightly in place with adhesive tape
Overwrap dressing above and below bite area with ACE bandage
Wrap ACE (elastic) bandage as tight as one would for a sprain. Not too tight.
Check for pulses above and below elastic wrap; if absent it is too tight
Immobilize bitten extremity, use splinting if available.
Try and keep bitten extremity below heart level or in a gravity dependent position

Go to nearest hospital or medical facility as soon as possible
Try and identify, kill and bring (ONLY if safe to do so) offending snake.

Source:http:\\www.xmission.com/~gastown/herpmed/snbite.html

9.2.2. Drying Ovens (expected 5/1/97)

9.3. Site Access

Do not enter any field that you do not have permission to enter. Prior to the experiment all requests for field access are to be directed to Tom Jackson. Do not assume that you can use a field without permission. During the experiment requests are to be made to the Site Manager (Table 14). Requests for installations and unplanned sampling made during the experiment will not be easy to satisfy. Tracking down a landowner and getting permission can take up to a half day of time by our most valuable people. These people will be extremely busy during the experiment. Therefore, if you think you will have specific needs that have not been addressed, solve the problem soon through image analyses or site visits.

9.4. Communications

It is strongly suggested that all groups have a cellular phone that will operate within the SGP region. This will aid logistics as well as safety.

9.5. Briefings

The default decision for the P3 and the soil moisture sampling is to assume it is on everyday. An aircraft briefing will be held in OKC each evening to discuss the next days flights.

10. DATA MANAGEMENT AND AVAILABILITY (revision expected 5/1/97)

All experiment participants will be required to contribute a final data product to the experiment data base. Those who choose not to contribute will still have access to the data when it has been quality controlled and published as a data report. Investigators with access to the preliminary data sets are not to redistribute the data. Before the experiment, all investigators will be asked to describe their contributions and to agree to these terms.

June 1997 - August 1997	Experiment
Sept. 1997 - Feb. 1998	Sub-team Data Processing and Analysis
March 1998	Workshop
March 1998 - August 1998	Team Data Quality Control
Sept. 1998	Publication and distribution of data (Version 1)

A data management plan will be developed in the near future. An outline of the scope is included in Table 16.

Table 16. Data Management Structure

Mission Observations (Land)	Mission Observations (Atmosphere)	Cooperative	GIS	Satellite
ESTAR	LASE	ARM	Soils	TM
C Band	Airborne Fluxes	NOAA	Topography	AVHRR
SWTIR	EC/BR Fluxes	Mesonet	Land Cover	GOES
CASI	Soundings		GPS	SSM/I
SLFMR				
TIMS				
Surface SM				
Profile SM				
Vegetation				

11. SCIENTIFIC INVESTIGATIONS

Investigators actively participating were asked to submit an abstracr describing their planned activities. These are included here as provided.

1. Meyers, Baldrocchi
2. Kustas, Schmugge, Jackson, Prueger, Hatfield, Sauer, Starks, Norman, Diak, Anderson, Doraiswamy
3. Starks
4. Miller, Mohanty, Tsegaye, Rawls
5. Daughtry, Doraiswamy, Hollinger
6. Entekhabi, McLaughlin
7. Entekhabi, Rodriguez-Iturbe
8. Barros, Bindlish, Yanming
9. Peters-Lidard
10. Kumar
11. Chauhan
12. Diak, Norman, Kustas
13. Finch, Burke, Simmonds
14. Browell, Ismail, Lenschow, Davis
15. Salvucci
16. Njoku
17. Houser, Shuttleworth
18. Laymon, Crosson, Fahsi, Tsegaye, Manu
19. van Oevelen, Menenti
20. Mahrt, Sun
21. Walker, Goodison
22. Mohanty, Shouse, van Genuchten
23. Famiglietti
24. Elliott, Senay
25. Islam
26. Doraiswamy, Daughtry, Jackson, Kustas, Hatfield
27. Wood, Jackson
28. Wetzel
29. Duffy

Investigator(s) Tilden P. Meyers and Dennis D. Baldocchi
Institutions(s): NOAA/Air Resources Laboratory Atmospheric Turbulence and Diffusion Div:
Title:Continuous Long-term Energy Flux Measurements within the GCIP Domain

Numerical regional and global scale models will continue to be used for future climate and hydrological assessments. However, predicted climate scenarios are sensitive to the surface layer processes such as evapotranspiration and soil moisture. Preliminary results have shown significant variations in predicted evapotranspiration from the land-surface submodels that are currently used. Observational data sets that allow for detailed testing for an annual cycle are few. The credibility of climate simulations depends on the predictive capabilities of the submodels used in the parameterizations of the physical and biological processes. Long-term continuous measurements of water and heat fluxes are needed to assess and reduce uncertainties in the land-surface models. The results from the proposed work plan will provide a data base that can be used directly to meet the first two objectives of the GCIP scientific plan which are (1) to determine the temporal variability of the hydrological and energy budgets over a continental scale, and (2) to develop and validate coupled atmosphere-surface hydrological models.

Continuous measurements of the surface energy balance components (net radiation, sensible heat flux latent heat flux , ground heat flux , and heat storage) will continue at the Little Washita Watershed Latent energy fluxes from the soil and canopy systems will be determined to provide a complete data set for (1) the evaluation of the surface layer submodels currently used in synoptic scale and general circulation models, and (2) the determination of seasonal probability distributions and statistics for evaluating predictive capabilities of models. Measurements of additional hydrological components include precipitation and soil moisture. Other measurements that will continue to be measured include solar and net radiation, air temperature and humidity, wind speed and direction, and soil temperatures. Biophysical data will include determinations of leaf area indices, stomatal conductance, and surface albedo. Data from these sites will be used to: 1) evaluate the temporal variability of surface fluxes as a function of season; 2) determine daily and weekly probability distributions of energy fluxes; 3) evaluate and test current surface-biosphere submodels that are currently used for both short and long term numerical weather prediction; 4) determine the relative latent energy contributions from the soil and vegetative components as functions of season; and 5) test a hierarchy of models for estimating the surface energy fluxes from standard meteorological data.

Sponsor(s): NOAA/OGP
Tilden P. Meyers
423-576-1245
FAX: 423-576-1245

FED EX: NOAA/ATDD 456 S. Illinois Avenue Oak Ridge, TN

Use of Optical and Microwave Remote Sensing for Mapping Surface Fluxes During the SGP Experiment

Investigators/Institutions:
Bill Kustas, Tom Schmugge & Tom Jackson/USDA-ARS Hydro Lab Beltsville, MD
John Prueger & Jerry Hatfield/USDA-ARS Soil Tilth Lab, Ames, IA
Tom Sauer/USDA-ARS SPA Fayetteville, AR
Pat Starks/USDA-ARS Grazing Lands Res. El Reno, OK
John Norman, George Diak & Martha Anderson/Univ. of Wisconsin, Madison WI
Paul Doraiswamy/USDA-ARS RS & Modeling Lab, Beltsville, MD

Radiometric temperature and passive microwave observations provide unique spatially distributed surface boundary conditions for surface energy balance modeling. Several relatively simple remote sensing models have recently been developed and tested with ground-truth measurements for computing the surface energy balance (Norman et al., 1995; Kustas and Humes, 1996; Anderson et al., 1997; Zhan et al., 1997). There has also been recent applications of remote sensing data from weather satellites in a simple hydrologic model for monitoring vegetation growth and predicting crop yields (Doraiswamy and Cook, 1995). These modeling algorithms will be applied to remote sensing data collected over the whole SGP study area, but with primary focus on the El Reno site where there will be ground truth hydrometeorological data collected by J. Prueger, B. Kustas, T. Sauer and P. Starks. These data will include standard weather data (wind speed, wind direction, air temperature, relative humidity, solar radiation and precipitation), the surface energy balance, and profiles of soil moisture, temperature and soil heat flux. There will be several aircraft flights with the TIMS instrument coordinated by Tom Schmugge for collecting high resolution thermal-IR data in the early and later morning in order to evaluate the the Two-Source-Time-Integrated-Model (TSTIM; Anderson et al., 1997) and the Dual-Source-Energy flux-Model (DSEM; Norman et al., 1995) with local flux observations. In particular, the high spatial resolution TIMS data can be used to evaluate how well the TSTIM model performs on small pixels and whether simple methods exist for interpolating 5 km flux estimates from GOES down to the small scale of 10's of meters. The daily surface moisture maps from the ESTAR passive microwave observations on the P-3 aircraft coordinated by Tom Jackson will be used to test a version of DSEM that uses surface moisture for surface energy flux predictions (Zhan et al., 1997). Landsat TM and NOAA AVHRR data for the study sites and surrounding area will be acquired, processed and mapped by Paul Doraiswamy. In addition, the ground-based measurements of evapotranspiration and soil moisture profile changes will be used for testing the hydrologic model predictions (Kalluri and Doraiswmay, 1995; Doraiswamy, et al., 1997). Once model validation/calibration is performed at the El Reno site, the models will be used with satellite data (i.e., LANDSAT, NOAA-AVHRR and GOES) for mapping fluxes over the entire SGP domain. These estimates will be compared

to regional fluxes derived from aircraft eddy correlation and LASE measurements.
References:

Anderson, M.A., J.M. Norman, G.R. Diak, W.P. Kustas and J.R. Mecikalski. 1997. A two-source time-integrated model for estimating surface fluxes using thermal infrared remote sensing. Remote Sensing of Environment [In Press]

Doraiswamy, P.C. and P.W. Cook. 1995. Spring Wheat Yield assessment using NOAA AVHRR data. Canadian J Remote Sens. 21:43-51.

Doraiswamy, P.C., P. Zara S. Moulin and P.W. Cook 1997. Spring wheat yield assessment using Landsat TM imagery and a crop simulation model. (Submitted to Remote Sensing of the Environ.)

Kalluri, S. and P.C. Doraiswamy. 1995. Modelling transpiration and water stress in vegetation from satellite and ground measurements. Presentation at the 1995 International Geoscience and Remote Sensing Symposium. Firenze, Italy , p1483-1487.

Kustas, W.P., and K.S. Humes. 1996. Sensible heat flux from remotely-sensed data at different resolutions. Chapter 8. In: Scaling up in Hydrology Using Remote Sensing (J.B. Stewart, E.T. Engman, R.A. Feddes and Y. Kerr editors) John Wiley and Sons London pp. 127-145.

Norman, J. M., W. P. Kustas and K. S. Humes. 1995. A two-source approach for estimating soil and vegetation energy fluxes from observations of directional radiometric surface temperature. Agricultural and Forest Meteorology 77:263-293.

Zhan, X., W.P. Kustas, T.J. Schmugge and T.J. Jackson. 1997. Mapping surface energy fluxes in a semiarid watershed with remotely sensed surface information. Preprint of the 13th Conference on Hydrology, American Meteorological Society, pp. 194-197.

Bill Kustas
bkustas@hydrolab.arsusda.gov
USDA-ARS-Hydrology Lab
Beltsville, MD 20705 USA
Voice: (301) 504-8498
Fax: (301) 504-8931

Title: Investigation of spatial distribution of soil water and heat flux.

Abstract: A series of Soil Heat and Water Measurement Stations (SHAWMS) have been installed on the Little Washita River Watershed (LWRS) which make profile measurements of soil temperature, soil heat flux, the three parameters of soil heat, and soil moisture. Data from the SHAWMS will be used to investigate the temporal and spatial variability of soil water and heat flux under rangeland condtions and to provide another source of groundtruth data for the ESTAR instrument. A limited number of SHAWMS will be installed on the Ft. Reno site under both natural rangeland and winter wheat fields to investigate differences in these fluxes for representative ground cover conditions in central Oklahoma.

Sponsor: USDA-ARS-Grazinglands Research Laboratory

References:

Patrick J. Starks
pstarks@grl1.ars.usda.gov
(405) 262-5291
fax (405) 262-0133
USDA-ARS-GRL
7207 W. Cheyenne St.
El Reno, Oklahoma 73036

Investigator: Doug Miller

Collaborators: Binayak Mohanty, Teferi Tsegaye, Walter Rawls

Title: Combining Soil Survey Information and Point Observations of Soil Physical and Hydraulic Properties to Improve the Extension of Pedo-Transfer Functions to Regional Areas.

Abstract:

Soil moisture is a much sought after parameter for a wide range of modeling and management applications. Direct measurement of soil water status, however, is an expensive, time-consuming exercise which is largely prohibitive beyond a few select areas. Previous work has shown the utility of "pedo-transfer" functions to predict the water retention curve or unsaturated hydraulic conductivity of the soil. These functions are based on commonly measured soil physical properties such as particle-size distribution, organic matter content, and bulk density. Pedo-transfer functions in combination with routine spatial information from soil survey and spatial information on topographic and land surface characteristics could potentially be used to improve regional estimates of soil moisture.

We will focus on combining spatial information from soil survey, topographic and land surface characteristics with point observations of soil physical properties and soil moisture content to improve soil moisture predictions. The Little Washita River Basin in the southwestern portion of the SGP97 operations area will be the location of detailed study and correlation of field observations of soil physical and hydraulic properties. Ground sampling for this work will be performed in conjunction with soil moisture sampling in support of the main remote sensing objectives of SGP97. Manpower for sampling and access to sampling sites may, necessarily, restrict our opportunities to obtain a full range of representative soil map units. However, it is our hope that we can obtain enough samples to be able to characterize several key combinations of soil, topographic, and land surface conditions which in turn may be used to test our ability to "scale up" to larger areas.

Sponsor: NASA through the Penn State EOS IDS Investigation of the Global Water Cycle

Spatial variability of biomass and fraction of absorbed PAR within the SGP97 site.

Craig Daughtry and Paul Doraiswamy, USDA/ARS Remote Sensing and Modeling Lab, Beltsville, MD
Steven Hollinger, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820.

Abstract:
Relationships between phytomass production and absorbed photosynthetically active radiation (PAR) have been reported for numerous plant species (Daughtry, et al., 1992). The fraction of absorbed PAR (f_A) may be estimated from multispectral remotely sensed data (Prince, 1991). Together these two concepts provide a basis for monitoring vegetation production using remotely sensed data. Our primary objective is to characterize the spatial variability of vegetation within the SGP97 site. We will sample fresh and dry phytomass, leaf area index (LAI), and f_A in approximately 60 fields and will extract the multispectral data for each field from Landsat TM scenes. Most of the fields for vegetation sampling will also be used for the gravimetric and profile soil moisture sampling. Global positioning system (GPS) data will be used to register the images and locate the sample sites within the images. Various models will be used to relate the multispectral and vegetation data (Moran et al., 1995) and to estimate phytomass in other fields of the SGP97 site. In addition, for selected fields of winter wheat, we will measure crop residue cover using line-transect methods (Morrison et al., 1993) and will estimate residue cover for other fields using multispectral data from Landsat and other sources (Daughtry et al., 1996). Anticipated products include land use/cover maps, maps of vegetation density, and crop residue cover maps for the SGP97 site. These data should be useful for developing and extending various surface energy balance models and vegetation assessment models from local to regional scales.

References:
Daughtry, C.S.T., K.P. Gallo, S.N. Goward, S.D. Prince, and W.P. Kustas. 1992. Spectral estimates of absorbed radiation and phytomass production in corn and soybean canopies. Remote Sensing Environment 39:141-152.

Daughtry, C.S.T., J.E. McMurtrey III, E.W. Chappelle, W.J. Hunter, and J.L. Steiner. 1996. Measuring crop residue cover using remote sensing techniques. Theor. Appl. Climatol. 54:17-26.

Morrison Jr, J.E., C Huang, D.T. Lightle, C.S.T. Daughtry. 1993. Residue cover measurement techniques. J. Soil Water Conserv. 48:479-483.

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Craig Daughtry	voice 301-504-5015
USDA-ARS Remote Sensing and Modeling lab	fax 301-504-5031
10300 Baltimore Ave	email
Beltsville, MD 20705	cdaughtry@asrr.arsusda.gov

Investigators/Institutions:

Dara Entekhabi, 48-331, MIT, Cambridge, MA 02139
Tel: (617) 253-9698
Fax: (617) 258-8850
Email: darae@mit.edu

Dennis McLaughlin, 48-209, MIT, Cambridge, MA 02139
Tel: (617) 253-7176
Fax: (617) 253-7462
Email: dennism@mit.edu

Title: Using Data Assimilation to Infer Soil Moisture from Remotely Sensed Observations: A Feasibility Study

Abstract:
A state-space formulation of the data assimilation problem is developed including the following components: near-surface soil moisture and subsurface profile dynamics, surface energy balance, multispectral radiobrightness, soil type and pedotransfer functions. The data assimilation model will be tested using data from numerical experiments whose statistics are derived from the SPG97 and Washita92 experiments.

Sponsor: NASA

References:

McLaughlin, D. B. , 1996: Recent advances in hydrologic data assimilation, Reviews of Geophysics, 977-984.

Investigators/Institutions:

Dara Entekhabi, 48-331, MIT, Cambridge, MA 02139
Tel: (617) 253-9698
Fax: (617) 258-8850
Email: darae@mit.edu

Ignacio Rodriguez-Iturbe, Dept. Civil Engineering, Texas A&M University, College Station, TX 77843
Tel: (409) 845-7435
Fax: (409) 845-6156
Email: iri9280@vms2.tamu.edu

Title: On Space-Time Organization of Soil Moisture Fields: Dynamics and Interaction with the Atmosphere

Abstract:

The decrease in second-order statistics of soil moisture random fields under aggregation may be estimated using scaling functions whose parameters vary in time (during dry-downs) in a predictable manner and whose parameters have known dependencies on soil and climate properties. We plan to use the multiple scale observations of soil moisture fields using a variety of platforms and sensors to characterize the required scaling functions. Next using simple models of dry-down and percolation, we intend to relate the parameters of these functions to soil and climate properties.

Sponsor: NASA

References:

Rodriguez-Iturbe, I., G. K. Vogel, R. Rigon, D. Entekhabi, F. Castelli and A. Rinaldo, 1995: On the spatial organization of soil moisture fields, Geophysical Research Letters, 22(20), 2757-2760.

Scaling Issues in the Retrieval and Modeling of Soil Moisture -- A Geomorphology Perspective

Ana P. Barros, Rajat Bindlish, and Li Yanming
The Pennsylvania State University

ABSTRACT

Remote sensing and the prospect of long-term monitoring of soil moisture over large areas offer unique opportunities in hydrologic science both for climate studies and for operational applications. Pertinent research issues include: 1) the formulation and accuracy of the algorithms used to transform the remotely-sensed signal (i.e. surface radiometric temperature) into estimates of soil moisture; 2) scaling and the relationship between the scale of measurement and data resolution; 3) data assimilation into operational mesoscale models. In this context, the objectives of our research are to:

1) investigate and quantify the functional dependencies between observed soil moisture dynamics at different scales and the forming and development factors that determine the properties of soils in their natural setting--climate, vegetation, topography and geology;

2) investigate and quantify the functional dependencies between remotely sensed brightness temperatures at different scales and soil forming and development factors;

3) elucidate the scaling mechanisms implicit in remotely sensed brightness temperatures at different resolutions, and determine the effective scale of measurement at each resolution;

4) use the results of 1), 2) and 3) to constrain a transformation model to retrieve soil moisture. Sensitivity analysis to will be conducted to evaluate model's accuracy and transportability;

5) evaluate the skill of a mesoscale model, specifically MM5, when remote-sensing estimates of soil moisture are used as surface boundary conditions in operational mode. The focus is on short to medium-range forecasts of surface temperature, humidity, and precipitation.

Multidimensional spectral analysis, system identification techniques such as cluster analysis and self-organizing neural networks, geostatistics and deconvolution methods will be used to identify soil-topography, soil-vegetation, soil-climate and soil-geology relationships. Data from SGP97 will be analyzed along with data from previous field experiments (e.g. Washita-92 and 94).

Sponsor: Partly sponsored by NASA.

Vertical Profiles of the Atmospheric Boundary Layer and Upper Air for the Southern Great Plains 1997 Field Experiment

Principal Investigator: C. D. Peters-Lidard
Environmental Hydraulics and Water Resources
School of Civil and Environmental Engineering
Georgia Institute of Technology, Atlanta, GA 30332-0355
tel: 404-894-5190; fax: 404-894-2677
e-mail: cpeters@ce.gatech.edu

Abstract
In support of the eventual goal to integrate remotely sensed observations with coupled
land-atmosphere models, Georgia Institute of Technology and the National Severe Storms Laboratory propose to provide vertical profiles of atmospheric pressure, temperature, humidity, wind speed and wind direction during the Southern Great Plains 1997 field experiment (June 17-July 11). Our sounding design is based on three science needs directly related to the existing objectives of the experiment:
(1) Provide boundary and initial conditions for coupled atmospheric-hydrologic modeling;
(2) Provide data necessary for atmospheric correction of thermal remote sensing; and
(3) Support water vapor and heat budget computations over the SGP97 domain.
In addition to these science needs, surface and boundary layer profiles will provide data to support the estimation of roughness lengths and stability correction functions and to study boundary layer top entrainment processes and vertical structure. We plan to deploy two sounding systems: one boundary layer and upper air sounding system and one tethersonde system collocated within the Little Washita River Watershed in the southern portion of the SGP97 domain. The launch times will coincide with the launch times of the ARM/CART IOP Sounding program, and will therefore provide complete coverage around the boundary of the SGP97 domain to support vapor budget computations.

Sponsor: NASA (Program Manager: Ming-Ying Wei)

References
Betts, A. K. and A. C. M. Beljaars, Estimation of effective roughness length for heat and momentum from FIFE data, Atmos. Res., 30, 251-261, 1993.

Peters-Lidard, C. D. and E. F. Wood, Spatial variability and scale in land-atmosphere interactions: 2. Model validation and results, submitted to Water Resour. Res., 1996b.

Ziegler, C. L and L. C. Showell, Chapter XII: Atmospheric Soundings in Hydrology Data Report Washita 1994, eds. P. J. Starks and K. S. Humes, NAWQL 96-1, USDA ARS, Durant OK, June 1996.

Investigator(s)/Institutions(s): Dr. Praveen Kumar, Hydrosystems Lab. # 2527B, 205 North Matthews Avenue, Department of Civil Engineering, University of Illinois, Urbana, Illinois 61801
(217)-333-4688
Fax (217)-333-0687
email: kumar1@uiuc.edu

Students:
Patricia Saco (saco@uiuc.edu)
Ji Chen (jichen@uiuc.edu)

Title: Estimation, Modeling and Simulation of Soil Moisture Variability and Surface Energy Balance Using Multisensor Measurements at Large Scales

Abstract:
In order to understand the feedback interaction between land and atmosphere we need a method to characterize the near surface soil-moisture variability and surface energy balance at a vast range of scales. Due to the formidable cost of making such measurements the strategy adopted is to make fine scale measurements of limited coverage embedded within coarse scale measurements of larger coverage using instruments on different platforms. The PI has recently developed a multiple scale conditional simulation (MSCS) technique [Kumar, 1996] to obtain soil moisture fields by combining the multisensor measurements (obtained at multiple scales). The technique uses multiple scale Kalman filtering algorithms for the estimation and a conditional simulation technique for obtaining realistic soil-moisture fields. It relies on a fractal model of soil moisture [Iturbe et al., 1995]. The method can be easily extended to multiple variable fields such as the energy balance components at the land surface. The objectives of our participation in the Southern Great Plains Experiment are to:
(a) Extensively validate the multiple scale conditional simulation technique for a wide range of scales and soil-moisture conditions;
(b) Apply it to multiple variable surface energy fields and assess its performance;
© Assess the impact of the conditionally simulated fields on the atmosphere.

Sponsor(s): National Aeronautics and Space Administration

References:
1. Kumar, P., Application of Multiple Scale Estimation and Conditional Simulation for Characterizing Soil Moisture Variability, submitted to {\em Water Resources Res.}, 1996.

2 Rodriguez-Iturbe, I., G. K. Vogel, R. Rigon, D. Entekhabi, F. Castelli, A. Rinaldo, On the Spatial Organization of Soil Moisture Fields, {\em Geophysical Res.

Letters}, 22(20), 2757-2760, 1995.

VEGETATION EFFECTS ON SOIL MOISTURE ESTIMATION

Narinder Chauhan
Code 923
NASA/Goddard Space Flight Center
Greenbelt MD 20771
301 286 4840
FAX: 301 286 1757
E-mail: nsc@fire.gsfc.nasa.gov

The estimation of soil moisture depends strongly on the vegetation and its quantization. I will be working with Paul Doraiswamy of USDA and David LeVine of GSFC/NASA for the characterization of vegetation. The plan is to participate in the collection of gross vegetation parameters such as plant density, LAI, vegetation water content, etc. for most of the vegetation in the area. In addition, specific vegetation types will be targeted for collection of detailed canopy geometry data. This can involve measuring canopy architecture, leaf and stem angle distributions. In the past, the measurement of soil moisture under certain crops, like grass and alfalfa has been a problem. The plan is to characterize such crops with a higher degree of accuracy and to use theory (Discrete Scatter Models) to compare predictions with passive microwave measurements. The goal is to learn how to characterize these vegetation canopies to accurately estimate soil moisture.

Investigators: George R. Diak and John M. Norman, University of Wisconsin-Madison
William P. Kustas ,USDA-ARS
Title of Investigation: Estimation and Validation of Evapotranspiration at 10 km Scales During The SGP-97 Experiment

Abstract:
We will investigate the performance of a two-source time-integrated model (TSTIM) for evaluating the surface energy balance over the domain of the SGP-97 experiment. This model is comprised of a surface component (describing the relationship between radiometric temperatures, sensible heat flux and the temperatures of the air, canopy and soil surface), coupled with a time-integrated component (connecting the time-integrated surface sensible heat flux with planetary boundary layer development). The required data inputs are radiometric surface temperatures at two times (from GOES), analyzed surface and upper air synoptic data, and vegetation cover estimates from satellite sources. Surface energy balance components will be estimated at approximately a 10-km resolution over the SGP-97 domain. These estimates will be compared with available surface and aircraft-based flux estimates. The TSTIM has the ability to utilize information on soil-surface evapotranpiration from any source. Using the SGP-97 data, we will also investigate how microwave-based near-surface soil moisture estimates from passive microwave sensors can be incorporated into this model.

References:

Anderson, M. C., J. M. Norman, G. R. Diak and W. P. Kustas, 1996: A two-source time integrated model for estimating surface fluxes for thermal infrared satellite observations. Accepted for publication, Rem. Sens. Environ.

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Norman, J. M., W. P, Kustas and K. S. Humes, 1995: A two-source approach for estimating soil and vegetation energy fluxes from observations of directional radiometric surface temperatures, Agric. For. Meteor., 77, 263-293.

Contact:
Dr. George R. Diak
CIMSS, University of Wisconsin-Madison
1225 W. Dayton St., #205
Madison, WI 53706
Phone: 608-263-5862 Fax: 608-262-5974

email: georged.@ssec.wisc.edu

Title: Estimating Soil Hydraulic Properties from Airborne Passive Microwave Data - The Effects of Subpixel Heterogeneity

Investigators/Institutions: J. Finch and E. Burke, Institute of Hydrology
L Simmonds, University Reading

Abstract:

A physically based model that couples a soil water/energy model to a microwave emission model (MICRO-SWEAT) has recently been developed. MICRO-SWEAT predicts the time series of microwave emission from input parameters of the soil properties, soil water status, vegetation parameters and a time series of meteorological data.

One application of MICRO-SWEAT has been to successfully estimate soil hydraulic properties from ground-based microwave data, i.e. essentially point measurements, by fitting the model to detailed time series of data. The next step in this line of research is to estimate soil hydraulic properties at the spatial scale of a pixel of remotely sensed data. The proposed research will investigate the effect of sub-pixel heterogeneity in soil hydraulic properties, soil roughness, vegetation water content and soil moisture on microwave data.

The objectives of the project will be achieved by using the microwave values predicted from MICRO-SWEAT. The ground and ESTAR data acquired during SGP’97 will provide a data set that contains both the input parameters for MICRO-SWEAT and microwave data that can be used to test the values predicted by the model. The proposed research will make additional measurements on the ground of the soil and vegetation parameters required by MICRO-SWEAT at a series of sites in order to quantify the spatial heterogeneity within a pixel of the ESTAR data. Between 50 and 100 sites will be selected to represent the variations in soil and vegetation and measurements of soil moisture taken daily except during periods of rapid change when a reduced number of sites will be monitored more frequently. Other parameters will be estimated at different periods reflecting their rate of change. The key input and validation parameters which will be measured are: rainfall, plant height, leaf area index and leaf angle, vegetation water content, surface soil moisture, TDR soil water down to 120 cm, surface roughness, soil bulk density. In addition, gravimetric soil moisture samples for calibration will be collected and soil samples will be taken for laboratory analysis. The field data will be analyzed to assess the temporal and spatial variability of the input parameters required by MICRO-SWEAT.

The first step of the modelling will be to test the values predicted by MICRO-SWEAT against the values recorded by the ground-based microwave radiometer in order to verify that the model is predicting the values to an acceptable accuracy. The next stage will be to use MICRO-SWEAT to predict the microwave emission from the range of soils and land cover types that occur within a pixel of the airborne remotely sensed data. These values will then be aggregated to produce a

time-series of ‘averaged’ values that will be tested against the values of the airborne remotely sensed data. A sensitivity analysis will be carried out to assess the contribution from the different land surface parameter combinations to the time series of ‘averaged’ remotely sensed data. Finally, the simulated times series of remotely sensed data will be inverted to estimate the soil hydraulic properties of the pixel and a comparison made between these values and the variability of the values actually occurring within the pixel.

Sponsor: UK Natural Environment Research Council

Staff:

Dr. Jon Finch
Institute of Hydrology
Wallingford
Oxon OX10 8BB
UK
tel. + 44 (0)1491 838800
fax. + 44 (0)1491 692424
email: J.Finch@ioh.ac.uk

Dr. Lester Simmonds
Soil Science Department
University of Reading
Reading RG6 6DW
UK
tel. +44 (0)1189 316557
fax. +44(0)1189 316660
email: asssimmo@reading.ac.uk

Miss Eleanor Burke
Institute of Hydrology
Wallingford
Oxon OX10 8BB
UK
tel. + 44 (0)1491 838800
fax. + 44 (0)1491 692424
email: E.Burke@ioh.ac.uk

Investigator(s)/Institutions(s):
Edward V. Browell, PI, NASA Langley Research Center,
Syed Ismail, co-I, NASA Langley Research Center,
Donald H. Lenschow, co-I, National Center for Atmospheric Research
Kenneth J. Davis, co-I, University of Minnesota

Title: INVESTIGATION OF MESOSCALE VARIABILITY IN CONVECTIVE BOUNDARY LAYER DEVELOPMENT USING LASE

Abstract:
One of the four objective of the Southern Great Plains 1997 (SGP97) Experiment is the examination of 'the effect of soil moisture on the evolution of the atmospheric boundary layer and clouds over the southern great plains”. This study seeks to advance our understanding of this coupled land-atmosphere system, a fundamental component of the hydrologic, weather and climatic systems. We will study the spatial variability in the development of the convective boundary layer (CBL) over a fairly uniform land surface with spatially varying soil moisture content. Soil moisture will be measured with ESTAR on-board the NASA P-3 aircraft. NASA's Lidar Atmospheric Sensing Experiment (LASE) will also be flow on-board the P-3 aircraft. The LASE instrument, reconfigured to fly on the P-3, will be capable of resolving the vertical and horizontal structure of the developing CBL, including information on the two dimensional moisture structure of the atmospheric boundary layer. LASE and ESTAR together will provide a unique and comprehensive mesoscale remote sensing data set for studying the evolution of the CBL and its relation to the land surface. This study will benefit from complementary data from the Canadian Twin Otter aircraft (real-time images of boundary layer structure obtained by LASE can be used, when appropriate, to guide the Twin Otter). Other in situ surface and tower measurements, and satellite remote sensing data will also be used in this study. The primary goals of this research are: evaluation of the influence of soil moisture on the local surface energy budget (SEB) over the SGP97 region; 2) evaluation of the influence of mesoscale spatial variability in the SEB on CBL development, including CBL depth and cloud cover; 3) quantification of the CBL water vapor budget (advection, entrainment, evapotranspiration) using remotely sensed and in situ data; and investigation of microscale mechanisms responsible for the entrainment of tropospheric air into the CBL.

Sponsor(s): NASA

References:

Kenneth J. Davis, Assistant Professor phone: 612-625-2774
Department of Soil, Water, and Climate fax: 612-625-2208
University of Minnesota email: kdavis@soils.umn.edu

1991 Upper Buford Circle St. Paul, MN 55108-6028

Investigator: Guido D. Salvucci, Boston University, Dept. of Geography
675 Commonwealth Ave., Boston, MA 02215
617-353-8344
Fax 617-353-8399
gdsalvuc@bu.edu

Title: Detection and modeling of transitions between atmosphere and soil limited evapotranspiration in the southern great plains summer 1997 experiment

Abstract:

Salvucci [WRR 33(1), 111-122, 1997] presented a simple diagnostic model of bare soil evaporation which expresses the daily rate of evaporation during soil limited periods as
a function of the duration (td) and average rate (ep) of stage-one (potential) evaporation. The model does not require in situ estimates of soil hydraulic properties or initial water content, as these are implicitly related to td and ep. Surface and remote observations
of detectable changes in near surface moisture content, temperature, and albedo may be used to estimate the transition time (td). With extensions to estimate stressed transpiration from grasses, the model thus has the potential to yield ET estimates over large areas using satellite data. The microwave estimates of soil moisture collected over the month long SGP experiment will be used in conjunction with concurrent surface flux measurements taken at the ARM sites to further test and develop this methodology, with
special emphasis on the detection of transition time via microwave-estimated surface soil moisture dynamics.

References: Salvucci, G.D., 1997. Soil and moisture independent estimation of stage-two evaporation from potential evaporation and albedo or surface temperature, Water Resources Research, 33(1), 111-122

Sponsor: NASA Grant NAGW-5255 "Thermal and Hydrologic Signatures of Soil Controls on Evaporation"

Investigator: Eni G. Njoku
Institution:Jet Propulsion Laboratory

Title: Multichannel land parameter retrieval at different spatial scales

Abstract:
Soil moisture is the dominant effect on microwave emission from soils at L-to C-band for soils with low to moderate vegetation. Surface roughness, temperature, and low-opacity vegetation cover affect soil microwave emission, but to lesser extents than soil moisture. As the opacity of vegetation cover increases it becomes the dominant effect on the microwave emission, and can mask the soil moisture signal. Multifrequency retrieval algorithms are a means for utilizing the varying sensitivity of brightness temperature to the surface parameters at different frequencies to correct for vegetation, roughness, and temperature in retrieving soil moisture. Theoretical simulations using models based on recent empirical data show that multichannel algorithms should work well in practice. However, there have been few opportunities to demonstrate this in actual field experiments. SGP'97 provides an opportunity for such a demonstration. Truck-based L-, S-, and C-band measurements are planned, providing data at a local scale, and L-band aircraft data and AVHRR satellite data will be available at the 1-km resolution scale. SSM/I data will be available at a 50-km resolution scale, providing a historical database of 19.3 and 37 GHz brightness temperatures over the SGP'97 site at that scale. We will
provide the AVHRR and SSM/I data to the SGP'97 experiment database as a contribution of this investigation. Soil moisture retrievals will be performed at three scales, using different algorithms and available data sets: (1) local - truck-based; (2) regional - aircraft microwave/satellite AVHRR; (3) time-series - satellite SSM/I. Soil moisture retrievals for
these cases will be compared with in-situ observations and output from numerical models over the SGP'97 site, and results of the analyses will be published. Research using the truck-based, aircraft, in-situ, and model data will be performed in collaboration with the data providers.

Sponsor:NASA Code Y

References:

Njoku, E.G. and D. Entekhabi (1996): Passive microwave remote sensing of soil moisture. J. Hydrology, 184, 101-129.

Njoku, E. G., S. J. Hook, and A. Chehbouni (1996): Effects of surface heterogeneity on thermal remote sensing of land parameters. In: Scaling Up In Hydrology Using Remote Sensing (J. B. Stewart, E. T. Engman, R. A. Feddes, and Y. Kerr, Eds.), Wiley, New York.

Investigator(s)/Institutions(s):
Paul R. Houser (NASA-GSFC), and Jim Shuttleworth (U. of Arizona)

Title: Regional In-Situ Profile Soil Moisture and Surface Energy Flux Observations in support of the 1997 Southern Great Plains Experiment.

Abstract:

Our contribution to the Southern Great Plains 1997 experiment will be in four areas: (1) general mission support through surface gravimetric sampling and processing, (2) profile soil moisture observations using TDR and gravimetric techniques, (3) Soil characterization at selected sites, and (4) operation of a surface energy and water flux station at the ARM central facility.

Observations of Profile Soil Moisture and Characteristics:
The primary objective of the Southern Great Plains 1997 (SGP97) Experiment is to map soil moisture using an airborne passive microwave radiometer (ESTAR, LeVine et al., 1992) over a 60 km by 250 km area in central Oklahoma for a one month period during the summer of 1997 (Jackson, 1996). Passive microwave instruments are only sensitive to moisture in the top few centimeters of soil, but knowledge of moisture in the entire soil profile is essential for hydrologic, ecologic, and climatic studies (Wei, 1995; Ragab, 1995; Jackson, 1980). Therefore, profile soil moisture observations will be essential for understanding the relationship between the remotely-sensed measurements and deeper moisture stores. Profile measurements will enable further development and validation of methodologies that extend remotely sensed surface soil moisture estimates to the entire root zone (Jackson, 1980), will enable the definition of vertical soil moisture error correlation structures which are essential in soil moisture data assimilation studies, and will help to calibrate existing profile sensors. Profile soil moisture observations using Campbell heat dissipation probes are currently in place in the SGP97 area at 14 Little Washita Micronet, 5 Oklahoma Mesonet, 2 ARM Central Facility, and 5 El Reno sites. Observations made with these sensors are known to vary with soil characteristics and temperature, therefore each of these sites will be instrumented with an ESI MoisturePoint profile TDR that will be monitored daily during SGP97 (installation done prior to the experiment by Pat Starks, USDA-ARS El Reno), and profile gravimetric observations at selected sites (mostly at El Reno) will be collected as frequently as possible (selected soil cores will be sent to the USSL for water retention, and soil characterization analysis). The TDR probes and MoisturePoint equipment for this plan are currently available (Pat Starks, USDA-ARS, and Ron Elliot, OK Mesonet), and both truck-mounted and hand operated gravimetric sampling equipment is available (USSL-Binayak Mohanty), but truck sampling may be limited to the EL Reno facility. The existing profile soil moisture sensors are located next to weather observation stations that are typically

on the edges of fields in non-characteristic soil and vegetation. To assess the representiveness of these observations, additional in-field TDR profile observations will be made at a subset of sites (2 at the ARM Central Facility, 2 at El Reno, and 1 at the Little Washita). It is thought that a minimum of 3 in-field TDR observations will be necessary at each of these sites to assess the field average profile soil moisture. At one site (El Reno) a larger number of in-field TDR observations (9 samples) will be made to determine if 3 samples is adequate for determination of in-field average profile soil moisture. Approximately 4 of these 21 additional probes are currently available (Pat Starks, USDA-ARS), leaving only ~17 to purchase ($350ea * 17probes = $5950)!

Observations of Surface Water and Energy Fluxes:
The DOE-ARM program has embarked on an extensive environmental observation program in the Oklahoma and Kansas area. As part of this program, observations of surface water and energy fluxes are being performed with eddy correlation and Bowen ratio techniques. To characterize the quality of these observations for use in applications
such as validation and calibration of regional land surface and atmospheric modeling projects, a well established eddy correlation system will be co-located with the ARM surface flux measurement sites at the ARM Central Facility.
The University of Arizona's CO_2/H_2O eddy correlation system (Shuttleworth) will initially be co-located with other mobile surface flux measurement systems at the EL Reno Facility for a period of a few days just prior to the SGP97 experiment for intercomparison. During this time, two other Campbell Licor Bowen Ratio systems may be deployed and maintained at El Reno as part of this project. The UA eddy correlation system will be re-deployed to the ARM Central Facility at the start of the SGP97 experiment. It will be located near the ARM Bowen ratio system in rangeland vegetation for two weeks, and near the ARM eddy correlation system in a winter wheat field for two weeks. The exact location and height of the UA system may vary from the ARM sensors to minimize fetch problems.

Personnel: Paul Houser (available for experiment duration)
Chawn Harlow (available for experiment duration)
Jim Shuttleworth (questionable availability)

Sponsor(s):
NASA-GSFC: Houser's salary, computer support, GPS
NASA-HQ: Houser's Travel, and hopefully some equipment
U of Arizona: NASA Contract NAS-5-3492 will provide salary and travel for 1 student, computer support, 1 flux station

Cooperator(s):
USDA-ARS (Pat Starks at El Reno): cooperating on MoisturePoint TDR

sampling
USDA-ARS-SL (Binayak Mohanty): Use of soil sampling equipment, possibly including a hydraulic press for use at El Reno
Oklahoma Mesonet (Ron Elliot): Use of 2-3 MoisturePoint "Boxes"

References:

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Ragab, R., 1995. Towards a continuous operational system to estimate the root-zone soil moisture from intermittent remotely sensed surface moisture. Journal of Hydrology, 173:1-25.

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Primary Contact:

Paul R. Houser
houser@hydro4.gsfc.nasa.gov
(301)-286-7702
fax (301) 286-1758
NASA's Goddard Space Flight Center
Hydrological Sciences Branch / Data Assimilation Office
Code 974 (Bldg. 22, Room C277)
Greenbelt, MD 20771

Participation in SGP97 from the
Center for Hydrology, Soil Climatology and Remote Sensing

The Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS) under NASA sponsorship has as one of its objectives to develop a Local-scale Hydrology Model (LHM) and a Regional-scale Hydrology Model (RHM) that can utilize periodic input of remotely-sensed soil moisture data to "adjust" the surface soil moisture field used to calculate root zone moisture. In addition, we recognize the need to address the issue of disaggregating large pixel soil moisture data from satellites to the process-scale represented in the hydrologic models. The Southern Great Plains 1997 (SGP97) Experiment will provide data necessary for HSCaRS to pursue its hydrologic modeling research objectives. HSCaRS will provide support to the SGP97 Experiment and acquire additional characterization information needed for hydrologic modeling by conducting research in the following five areas:

1.) Relate surface soil moisture measurements to the soil moisture profile:
We will install and operate a soil profile station (see description below) on each of the two plots in the vicinity of the calibration plots to relate the observed surface soil moisture to the underlying soil moisture profile. One energy balance Bowen ratio (EBBR) station is available for deployment at the SLMR calibration site to relate soil moisture changes to surface energy fluxes. Depending on which site is selected for the calibration site, instead we may choose to deploy the EBBR in the Little Washita River basin. Additional meteorological measurements, including rainfall, air temperature, relative humidity, shortwave and infrared radiation wind direction and speed will be made at the SLMR site. Chip Laymon (GHCC) will service these stations and will also assist Peggy O'Neill in SLMR operation and data acquisition.

Up to four additional soil profile stations will be deployed in the Little Washita River watershed to a.) provide additional points for relating remotely-sensed surface soil moisture to the underlying soil moisture profile, b.) to relate SHAWMS soil profile measurements at field borders to measurements within the field, and c.) provide time continuity to periodic manual soil moisture profile measurements to be made at approximately 20-30 sites in the SGP97 study area (coordinated by Paul Houser). Bill Crosson (GHCC) will be the lead on this activity.

Description of Soil Profile Stations:
Soil moisture and temperature measurements will be made at several depths down to about 75 cm in each pit. Soil moisture will be measured using Water Content Reflectometers (Campbell Scientific, Inc.), a device based on time domain reflectometry, and using Soil Moisture Probes (Radiation and Energy Balance Systems), a device based on electrical resistance. Soil temperature will be measured in each pit using soil thermistors. Ground heat flux will be determined using a heat flux plate installed at 5 cm depth plus the heat storage in the upper 5

cm layer calculated from the time rate of change of temperature, which is measured using 4-sensor averaging thermocouple probes installed at 1, 2, 3 and 4 cm depths. We are currently examining techniques to derive the soil dielectric constant from Water Content Reflectometers or similar sensors. At this point this appears feasible; if so, we will provide dielectric constant profiles at one or more of the profile stations. This information should be valuable in understanding both SLMR and ESTAR measurements vis-α-vis soil moisture measurements in the upper 5 cm as well as in the profile.

2.) Soil hydraulic property characterization:
Accurate knowledge of the spatial distribution of soil hydraulic properties is necessary for SGP97 soil moisture retrieval as well as for hydrologic modeling activities. Soil profiles will be described and sampled for texture, hydraulic conductivity, bulk density and porosity at the sites where the HSCaRS soil profile stations are installed. A representative grass and winter wheat field in the Little Washita River watershed will be sampled (up top 100 samples each) for surface hydraulic properties. All soil samples will be analyzed at Alabama A&M University. Teferi Tsegaye (Alabama A&M University) will be lead on this activity.

3.) Classify vegetation:
An accurate land cover classification is necessary for the SGP97 soil moisture retrieval algorithm and subsequent hydrologic modeling. Landsat TM data will serve as the basis of the classification. HSCaRS will provide personnel to support this effort being coordinated by other SGP97 team scientists. Ahmed Fahsi (Alabama A&M University) will assist in this activity and coordinate additional student support provided by Alabama A&M University.

4.) Surface soil moisture variability:
Some understanding of the spatial variability of surface soil moisture is required to a.) assess the accuracy of using a limited number of gravimetric samples for remote sensing verification, b.) assess the accuracy of the remote sensing technique to represent the mean surface moisture of the field, c.) assess the linearity of integrating moisture variability by the ESTAR instrument within a single pixel, d.) test mixed-pixel algorithms, and e.) evaluate field- and sub-watershed-scale hydrologic processes. While this activity will be conducted with a large cooperative group from many institutions, HSCaRS scientists from GHCC and Alabama A&M University have contributed significantly to developing the science and implementation plans for this activity. Teferi Tsegaye has particular interest in studying field-scale variability and Chip Laymon and Bill Crosson have interests in the application of these data to remote sensing interpretation and verification of hydrologic models.

In addition to field sampling, Chip Laymon is developing a GIS application for rapid mapping and evaluation of the field measurements. Site information and field measurements will be downloaded nightly from portable data recorders to a PC. These data can then be uploaded into a GIS application and for mapping and production of soft and hard copy output and thereby used by the field team leaders in redirecting labor resources the next day. In addition, near "real-time" visualization of the field measurements will contribute greatly to morale by making the science more tangible and understandable to those participating.

5.) Develop and test surface TDR measurement capability:
The surface soil moisture variability study (#4 above) is dependent on a portable, rapid measurement technique. Recent advances in time domain reflectometry techniques have resulted in sensors with "on-board" signal processing. We are currently investigating the ability to modify several off-the-shelf products for use in surface (0-5 cm) soil moisture
determination. Preliminary results indicate that we will be successful in providing an instrument for use during SGP97. Current research is focusing on sensor intercomparison and calibration. Recommendations on equipment are forthcoming.

HSCaRS Participants:
Global Hydrology and Climate Center
Chip Laymon week 1, 2, 4
chip.laymon@msfc.nasa.gov

Bill Crosson week 1, 3, 4
bill.crosson@msfc.nasa.gov

Vishwas Soman
vishwas.soman@msfc.nasa.gov

Alabama A&M University
Ahmed Fahsi afahsi@asnaam.aamu.edu
Teferi Tsegaye tsegaye@asnaam.aamu.edu
Andrew Manu amanu@ asnaam.aamu.edu
Rajbhandari Narayan rajbhandari@asnaam.aamu.edu
~ 5-8 grad. students 2 week each ?

Investigator(s)/Institution: P.J. van Oevelen, Dept. Water Resources, WAU, Wageningen, The Netherlands
M. Menenti, Winand Staring Centre, Wageningen, The Netherlands

Title of Investigation: Estimation of spatial soil moisture fields estimation using sensor fusion: SSM-I, ERS, Radarsat and ESTAR

Abstract:

Microwave radiometry has been widely accepted as the most practical tool to estimate spatial soil moisture fields, especially at L-band the results have been encouraging. However, currently there are no spaceborne microwave radiometers available with an acceptable resolution to be used in watershed studies. Therefore, the usefulness of SAR, in particular Radarsat and ERS, to estimate the same type of soil moisture fields as is possible with the airborne ESTAR (at a resolution of 1 km) will be investigated. The combination of data originating from various sensors to estimate the same property is referred to as sensor fusion. Within the EOS framework this study will also investigate the usefulness of low resolution SAR systems such as ASAR and the application of these fields in Numerical Weather Prediction models. To facilitate this study an extensive soil moisture measurement campaign will be set-up using portable TDR's (Time Domain Reflectometry), an FD (frequency domain) sensor along transects/grids and the EM38 instrument to give a more spatially average measurement over the same transect/grid. The grid size and spatial sampling scheme should be set up such that the the measurements are representative enough to cover the spatial resolutions of the various sensors (25m up to 1 km). All these measurements should occur as closely as possible to the overpass times of the various instruments.

Sponsor: Netherlands Remote Sensing Board/SRON

References:

Investigator(s)/Institutions(s): Larry Mahrt (Oregon State University) and Jielun Sun (University of Colorado/NCAR)

Title: Aircraft measured surface fluxes and relationship to soil moisture.

Abstract: The Canadian Twin Otter and the NOAA LongEZ will be deployed during SGP to measure the spatial variability of fluxes of heat, moisture and carbon dioxide. The LongEZ will fly primarily low level flights below 50 m (subject to final FAA approval) to concentrate on surface flux measurements while the Twin Otter will fly multiple levels to include vertical structure of the boundary layer and assessment of entrainment of dry air. Two principal modes of operation will be "chasing" spatial gradients of surface moisture and coordinated flights with the P3. Additional flights will feature tower-aircraft flux comparisons.

The aircraft data, and eventually the tower flux, Mesonet and sounding data will be archived at Oregon State. The aircraft data will be quality controlled and evaluated in terms of flux sampling errors. The analyzed fluxes will be provided to the community along with a suite of other processed parameters such as surface roughness and surface radiation temperature. The analyzed fluxes from the two aircraft will be combined with the sounding data, the Mesonet data, LASE water vapor measurements, ESTAR brightness temperature and the soil moisture estimates to examine the response of the boundary layer to spatial variations of the soil moisture and the feedback of boundary layer evolution on the surface moisture fluxes. For example surface dryer conditions lead to greater heat flux, boundary layer growth and entrainment drying which reduces the surface relative humidity. For a given soil moisture, this enhances the soil moisture loss. Its effect on transpiration depends on stomatal control.

Methods are being developed to estimate area averaged moisture fluxes by modelling the evaporative fraction in terms of remotely sensed variables including the surface radiation temperature, red and near infrared channels and microwave band.

Sponsor(s):NSF/NASA

Larry Mahrt
COAS OSU
Corvallis, OR 97331
mahrt@ats.orst.edu 541 737 5691 fax 2540

Jielun Sun
MMM NCAR
P.O. Box 3000
Boulder, CO 80307
jsun@elder.mmm.ucar.edu 303 497 8994 fax 8171

Investigators/Institutions:Ms. Anne Walker, Dr. Barry Goodison
Climate Research Branch, Atmospheric Environment Service
4905 Dufferin Street, Downsview, Ontario, Canada, M3H 5T4
Phone: (416)739-4357 (Walker), (416)739-4345 (Goodison)
Fax: (416)739-5700
E-mail: Anne.Walker@ec.gc.ca, Barry.Goodison@ec.gc.ca

Title: Soil Moisture Determination Using 19 GHz Airborne Microwave Radiometry

Abstract:
Passive microwave data have been used successfully by the investigators to derive snow cover, sea ice and lake ice elements of the cryosphere. Soil moisture has been identified as a significant weakness in climate, forecasting and hydrological models with land surface/atmosphere interaction schemes. Much research has been conducted using low frequency passive microwave data (e.g. 1.4 GHz), but as yet there is no satellite platform containing a low-frequency passive microwave radiometer. In 1996, the investigators participated in a joint experiment (REBEX-IV) with the University of Michigan, where microwave emission data were acquired from July to September for bare soil and grass-covered sites using ground-based microwave radiometers. Based on the REBEX-IV observations over bare-soil, there appears to be some sensitivity to surface soil moisture (perhaps more appropriately described as surface soil wetness) at the 19 GHz frequency. Since the current satellite radiometer, SSM/I, has 19 GHz channels, further investigation of the potential of this frequency for soil wetness determination in mid-west prairie environments at scales other than point or field size is warranted. Aircraft flights provide the opportunity to assess the sensitivity of the 19 GHz frequency for varying soil moisture conditions over a larger area and over varying cover conditions than is possible with ground-based systems, for the purposes of scaling up to satellite spatial resolutions and the challenge of the mixed pixel (bare and vegetated) common to the Canadian prairie region, which is the ultimate region of concern.

The Atmospheric Environment Service (AES) has a set of 3 microwave radiometers (19, 37 and 85 GHz) which have been flown on the National Research Council's Twin Otter aircraft for targeted research missions over the past 2 years. The NRC Twin Otter has been commissioned by NASA to acquire flux measurements during the SGP'97 experiment. We propose to take advantage of the NRC Twin Otter being on-site at SGP'97 and fly the AES 19 GHZ radiometer for targeted flights during a one week period within the SGP'97 time frame. These flights would be scheduled separately from the flux missions. A ground survey team will be used to acquire coincident soil moisture measurements along calibration segments of the flight lines. Access to other aircraft and ground-based measurements acquired during SGP'97 will enhance our analysis. Flight lines and ground survey would be co-ordinated with other investigations to benefit the entire mission.

Sponsors: Costs associated with this investigation (e.g. aircraft flights, personnel travel) will be funded from our organization's budget. Our proposed project is dependent on the NASA-funded participation of the NRC Twin Otter in SGP'97 for the flux missions. As this may be viewed as a mission of opportunity, we plan to co-ordinate all flight opportunities and field surveys in the scope of the entire mission. Our participation is also dependent on the resolution of possible technical difficulties with operating the microwave radiometers in a high temperature environment (currently being addressed by NRC).

SGP-97: An Integrated Validation Framework

Investigators: B.P. Mohanty, P. Shouse, M. Th. van Genuchten (U.S. Salinity Lab)

Rationale:

The spatio-temporal dynamics of water and energy transport across the soil-atmosphere boundary layer in relation to climate change, hydrology, near-surface thermodynamics, and land use is still poorly understood. The problem of accurately estimating regional-scale soil water contents of the near-surface, variably-saturated (*vadose*) zone is complicated by the overwhelming heterogeneity of both the soil surface and the subsurface, the highly nonlinear nature of local-scale water and heat transport processes, and the difficulty of measuring or estimating the subsurface unsaturated soil-hydraulic functions (the constitutive functions relating soil water content, soil-water pressure head and the unsaturated hydraulic conductivity) and soil thermal properties (heat capacity and soil thermal conductivity). As remote sensing techniques make it increasingly possible to obtain large-scale soil water content and heat flux measurements, validation of these measurements using ground-based data and/or indirect estimates from relevant *soil, landscape, and vegetation* parameters is essential.

Objective:

The overall objective of our project is to develop and evaluate an “integrated validation framework” for remote sensing data of soil moisture content in the shallow subsurface. Specific scopes of our investigation for SGP-97 experiment will include:

1. Coupling of digital soil maps (e.g., SSURGO, STATSGO) with soil hydraulic and thermal property databases (e.g., UNSODA) using ARC/INFO geographical information systems (GIS) and neural network (NN) based pedotransfer functions (PTFs) (*in collaboration with Doug Miller, and others*).
2. Identification of important soil (e.g., soil type, texture, porosity, bulk density), landscape (e.g., slope, aspect, elevation, depth to water table), and land use/cover (vegetation type, vegetation density, management practice, etc.) parameters for establishing pedotransfer functions to describe soil hydrologic and thermal properties of relatively large land areas (*in collaboration with Jay Famiglietti, Charles Laymon, Doug Miller, Paul Houser, and others*).
3. Measurement of soil water retention and hydraulic conductivity functions across the space and time domains of SGP-97 experiment (*in collaboration with Paul Houser and others*).
4. Investigation of the suitability of different exploratory data analyses, Bayesian statistics, spatial statistics, numerical or other up-scaling techniques for estimating effective soil hydraulic and thermal parameters of the larger land areas (pixels) from point measurements in the vadose zone (*in collaboration with Dennis McLaughlin, and Dara Entekhabi*).

The ultimate purpose of this research is to obtain pixel-scale estimates of the soil hydraulic and soil thermal properties for possible use in land-soil-atmospheric interaction simulation models to test space-borne measurements of transient soil moisture and soil temperature data, thereby yielding alternative (provide supplementary data) to ground-truth measurements.

Investigator/Institution: Jay Famiglietti, University of Texas at Austin

Title: Ground-Based Investigation of Spatial-Temporal Soil Moisture variability in Support of SGP '97

Abstract: Surface (0-5 cm) soil moisture exhibits a high degree of variability in both space and time. However, larger-scale remote sensing integrates over this variability, masking the underlying detail observed at the land surface. Since many earth system processes are nonlinearly dependent upon surface moisture content, this variability must be better understood to enable full utilization of the larger-scale remotely-sensed averages by the earth science community. The overall goals of this investigation are to (a) characterize soil moisture variability at high spatial and temporal frequencies; (b) understand the processes controlling this variability (e.g. precipitation, topography, soils, vegetation); and
© determine how well this variability is represented in a time series of 1-km (approximately) remotely-sensed soil moisture maps. Specific tasks are to (a) quantify the spatial-temporal variability of surface moisture content (mean, variance, distributional form, spatial pattern) in selected, representative quarter sections by means of supplementary sampling; (b) assess the accuracy of the remotely-sensed soil moisture maps by comparing ESTAR-derived mean moisture contents to those observed in the field; © assess the representativeness of remotely-sensed maps of mean moisture content with respect to the underlying variance within quarter sections; (d) determine how well larger-scale (full section to small watershed scale) observed patterns of soil moisture are preserved by the remotely-sensed maps; and (e) characterize the processes controlling soil moisture variability from the quarter-section to the small watershed scale, with implications for the environmental factors which influence spatial-temporal variations in the accuracy and representativeness of the remotely-sensed soil moisture maps.

A team of seven researchers (listed below) will conduct this investigation and will be on site for the full duration of the experiment. Site selection and the spatial-temporal frequency of intensive sampling are currently under investigation in collaboration with other SGP investigators. A portable sampling methodology, critical to the feasibility of this effort, is also under study at MSFC with promising results to date.

Beyond the implications outlined above, the proposed research will also have significance with respect to: sensor sensitivity and the design of future instruments; the potential utility and success of larger-scale remote sensing (i.e. in the presence of greater heterogeneity); improved understanding of soil moisture variability across spatial-temporal scales and its role in land-atmosphere interactions; and the parameterization of soil moisture and related processes in models of land surface hydrology.

Sponsors: NASA, NSF, University of Texas Geology Foundation

Participants:

Monika Bartelmann	Tel: 512-471-5762	pvb@mail.utexas.edu
Marcia Branstetter	Tel: 512-471-8547	marcia@maestro.geo.utexas.edu
Johanna Devereaux	Tel: 512-471-8547	jdev@mail.utexas.edu
Karen Devlin	Tel: 512-471-8547	kdevlin@maestro.geo.utexas.edu
Jay Famiglietti	Tel: 512-471-3824	jfamiglt@maestro.geo.utexas.edu
Steve Graham	Tel: 512-471-5023	steveg@mail.utexas.edu
Matt Rodell	Tel: 512-471-5762	mattro@mail.utexas.edu

All at: Department of Geological Sciences, University of Texas at Austin
Austin, TX 78712, Fax: 512-471-9425

INVESTIGATORS: Ronald L. Elliott, Professor and Gabriel B. Senay, Post-Doctoral Fellow

INSTITUTION: Biosystems & Agricultural Engineering Dept. Oklahoma State University
Stillwater, OK

TITLE: In-Situ Soil Moisture Intercomparisons and Scale-Based Validation of an T/Soil Moisture Model

ABSTRACT:
Our investigations will be focused on two topics: (1) intercomparisons of soil moisture measurements; and (2) validation of evapotranspiration/soil moisture modeling at various spatial scales. These investigations will depend on ground and remote sensing data that are collected during the SGP97 experiment, as well as measurements that are made on an ongoing basis in Oklahoma. Analyses related to topic (1) will be conducted in the relatively near term, whereas studies of topic (2) will be longer term in nature.

(1) The senior investigator has been directly involved in the addition of soil moisture sensors to 60 of the 114 Mesonet sites across Oklahoma. These sensors include a single TDR (time domain reflectometry) probe that provides layered data from five soil depths down to 90 cm, and four heat dissipation devices which are installed at depths of 5, 25, 60, and 75 cm. The TDR measurements are made periodically and provide data on volumetric water content, whereas the heat dissipation sensors are logged continuously and provide data on soil water potential. We not only seek to check the consistency between these two sources of data, but also to develop a soil- and sensor-specific calibration of the heat dissipation sensors to volumetric water content. The more intensive TDR sampling that will be done as part of SGP97 will enable us to expand these calibration data sets for the Mesonet sites in the study area. Furthermore, the surface (and perhaps profile) gravimetric sampling that will be done as part of SGP97 will provide a third, independent set of soil moisture data. With soil bulk density information from the sampling sites, the gravimetric data will be converted to volumetric water content and compared to the in-situ measurements. The OSU investigators will help to support the gravimetric sampling in the northern part of the SGP97 study area.

(2) The investigators and their colleagues are developing a GIS-based simulation model for estimating daily latent heat flux (evapotranspiration) and soil moisture at various scales across a heterogeneous landscape. The model is physically based, tracks the soil water balance, and makes use of three data "layers" -- soil, vegetation, and weather. The highest resolution data layers consist of 4-hectare cells, each of which is considered homogeneous. Mesonet sites are well suited for validating the model at "points", but it becomes much more problematic to validate at larger scales. Soil moisture and surface flux measurements from SGP97 will

provide a valuable data set for checking the model at various space (and time) scales.

SPONSORS:
This work will be funded through the combined support of the Oklahoma Agricultural Experiment Station and the Oklahoma NSF and NASA EPSCoR programs.

Investigator(s)/Institutions(s): Shafiqul Islam, University of Cincinnati

Title: Scaling Properties of Soil Moisture Images

Abstract: An outstanding research question critical to the integration of remotely sensed soil moisture into global models is how adequately the inherent spatial heterogeneity is represented at scales commensurate with current generation mesoscale and global climate models. To address this question, a framework is needed that can bridge the scale gap between the scale of remote sensors and large scale model resolution which can take into account the role of spatial heterogeneity. Recent research on spatial rainfall and streamflow has shown that they may exhibit scaling-multi scaling characteristics (Gupta and Waymire 1990). Our analysis of remotely sensed soil moisture images from Washita '92 experiment has shown that soil moisture also exhibits multi scaling properties (Hu et al.,1997). We hypothesize that the soil moisture images can be decomposed into large scale feature parts and small scale fluctuation parts. This decomposition will not make any apriori assumption regarding the structure of the soil moisture fields. Our preliminary results suggest the presence of simple scaling for the small-scale fluctuation parts. The limitations imposed by the data have allowed only three levels of decomposition and it is not clear over what range of scales such simple scaling exists. Using SGP97 data, we will explore and hopefully establish a relationship among the multi scaling properties observed in rainfall, soil moisture, and other land surface variables.

Sponsor(s): NSF and NASA

References:

Gupta, V.K. and E. Waymire (1990): "Multiscaling properties of spatial rainfall and river flow distributions", J. Geophys. Res. 95 (D3), 1999-2009.

Hu, Z., S. Islam, and Y. Cheng (1997): "Statistical characterization of remotely sensed soil moisture images", in press, Remote Sensing of Environment.

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Investigator(s)/Institution(s): Shafiqul Islam, University of Cincinnati, Elfatih Eltahir, Massachusetts Institute of Technology

Title: Relative Merits of Microwave Measurements of Soil Wetness and Radar Measurements of Rainfall for the Purpose of Estimating Soil Moisture Profile

Abstract: Recent studies in land-atmosphere interactions have shown that large scale soil moisture information as well as estimate of the soil water within the soil column is essential for accurate partitioning of surface fluxes. Current microwave measurements of soil moisture provides an excellent estimate of the soil water content within the top few centimeters. For the first time entire United States will be covered by the NEXRAD systems that would provide very detailed spatial information of rainfall. We plan to explore a fusion approach that combines microwave measurements of soil moisture and radar measurements of rainfall within a coupled land-atmosphere model to infer the soil moisture profile. In this experiment, we would also compare and contrast the relative merits of microwave (for soil moisture) and radar (for rainfall) to infer soil moisture profile within a single- and multi-sensor mode. The planned SGP97 data set would be an ideal test bed to examine the validity of this proposed approach of multi-sensor

fusion for soil moisture profile estimation.

Sponsors: University of Cincinnati and Massachusetts Institute of Technology

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Shafiqul Islam
Cincinnati Earth System Science Program
Department of Civil and Environmental Engineering
University of Cincinnati   Phone: (513) 556-1026
P.O. Box 210071   Fax: (513) 556-2599
Cincinnati, Ohio 45221-0071   email: sislam@fractals.cee.uc.edu

Investigators/Institutions:
Paul Doraiswamy and Craig Daughtry, USDA/ARS, Remote Sensing and Modeling Laboratory, Beltsville, MD
Tom Jackson and Bill Kustas USDA/ARS, Hydrology Laboratory, Beltsville, MD
Jerry Hatfield, USDA/ARS, Soil Tilth Laboratory, Ames, IA

Title of Investigation:
Study the techniques for retrieval of biophysical parameters from remote sensing and evaluate models for Leaf Area Index, Biomass and Energy balance of different canopies in the SGP experiment site.

Abstract
The seasonal vegetation dynamics will be monitored, using Landsat TM and NOAA AVHRR imagery acquired between May through July 1997. Ground measurements of LAW and green biomass will be monitored during the June-July period by Craig Daughtry. Several canopy models estimating surface reflectance (Verhoef, W., 1984), LAI (Clevers, J.G.P.W. et al., 1989 & Rahman H. et al., 1993) and biomass (Moran, M.S. et al., 1995) will be tested for their applicability in three major types of vegetative cover in the SGP study area. Biophysical parameters retrieved from remote sensing using several models will be evaluated. The extrapolation of parameters from field to region scales using models will be investigated for monitoring the vegetation dynamics throughout the summer period. Landsat TM and AVHRR data will be processed to provide good registration accuracy for correlation with ground samples collected through the study period.

Soil moisture and surface energy balance modeling to extrapolate measurements from aircraft and flux stations to the surrounding areas will be investigated in collaboration with T. Jackson and W. Kustas. Geospatial statistical analysis of soil, vegetation, and atmospheric parameters measured on the ground will be used in developing models to study techniques for extrapolating parameters from small to large areas.

References

Clevers, J. G. P. W., (1989), "The application of a weighted infrared-red vegetation index for estimating leaf area index by correcting for soil moisture", Rem. Sens. Environ., 29:25-37.

Moran, M.S., Maas, S.J., and Pinter, P.J., Jr. (1995). Combining Remote sensing and modeling for estimating surface evaporation and biomass production. Remote Sensing Reviews. 12:335-353.

Verhoef, W., (1984), "Light scattering by leaf layers with application to canopy reflectance modeling: the SAIL model", Rem. Sens. Environ., 16:125-141.

Utilizing Data from the Southern Great Plains Experiment with RADARSAT Data

Eric F. Wood, Princeton University, Princeton, NJ 08544
T. J. Jackson, USDA ARS Hydrology Lab

The goal of our participation in the Southern Great Plains Experiment is to develop improved remote sensing techniques for areal estimation of soil moisture, and to demonstrate that RADARSAT, either alone or in conjunction with other satellite and hydrologic observations, can provide soil moisture fields at regional scales. To date, the application of microwave radar remote sensing to soil moisture estimation has been hampered by several difficulties, including its sensitivity to vegetation and surface roughness, and understanding the relationship between observations from remote sensing instruments and point measurement values.

The planned research activities are the following:

1. Field data collection. In discussion with Tom Jackson, we plan to participate and focus our collection at the USDA El Reno site. We are assuming that this site will have a surface flux station so point water and energy balance modeling can be carried out, post experiment. We are also planning on utilizing field scale data collected in the Little Washita and point measurements from the CART-ARM sites. These data will help us extend the research to scales more consistent with regional estimation.
2. Soil moisture retrievals. Test and develop calibration strategies for soil moisture retrieval algorithms for the RADARSAT satellite data using the above field data., and estimate spatial maps of soil moisture. This work will build on research developed under our SIR-C funding.
3. Analyses. Intercompare remotely sensed soil moisture maps derived from RADARSAT with those developed from airborne ESTAR passive microwave sensors,
and with field data collected at El Reno, Little Washita and CART-Arm sites
4. Scaling. Study the scaling behavior of both airborne and satellite radar and derived soil moisture fields so as to develop strategies for regional soil estimation with lower resolution data than that collected in the SGP Experiment.

The anticipated results of the research include an improved understanding of and estimation abilities for soil moisture at catchment to regional scales, and to understand the relationship between remotely sensed soil moisture and ground observations.

Eric F. Wood
Department of Civil Engineering
Princeton University
Princeton, NJ 08544
Tel: 609-258-4675
Fax: 609-258-2799
(efwood@ceor.princeton.edu)

Investigator/Institution: Peter J. Wetzel/NASA GSFC
Title of investigation: Validation of PLACE land surface model using SGP97 observations

Abstract: The SGP97 experiment provides a unique opportunity to validate land surface models on scales ranging from point to regional. As part of the ongoing validation of the PLACE (Wetzel and Boone, 1995) model, data from SGP97 will be applied to provide initial conditions for the model and to validate the model's predictions of soil moisture (Wetzel et al 1996; Boone and Wetzel 1996) and of evaporative fluxes. Eventually it is hoped that a data set can be developed which will be used for validation of other land surface models participating in the Project for Intercomparison of Land surface Parameterization Schemes (PILPS).

Sponsor: NASA HQ

References:

Wetzel, P. J., and A. Boone, 1995: A parameterization for land-atmosphere-cloud exchange (PLACE): Documentation and testing of a detailed process model of the partly cloudy boundary layer over heterogeneous land, J. Climate, 8, 1810-1837.

Wetzel, P. J., X. Liang, P. Irannejad, A. Boone, J. Noilhan, Y., Shao, C. Skelly, Y. Xue and Z.-L. Yang, 1996: Modeling vadose zone liquid water fluxes: Infiltration, runoff, drainage, interflow, Global and Planetary Change, 13, 57-71.

Boone, A., and P. J. Wetzel, 1996: Issues related to low resolution modeling of soil moisture: Experience with the PLACEmodel, Global and Planetary Change, 13, 161-181.

Investigator(s)/Institution(s): Christopher J. Duffy
Civil and Environmental Engineering Dept., 212 Sackett Bldg Penn State University University Park, PA 16802
(814) 863-4384 (814) 863-7304 fax cjd@ecl.psu.edu

Title of investigation: Hydrogeologic Reconnaissance SG97

Abstract:

This investigation will involve field, library and agency (state, federal) research in order to compile available hydrogeologic data for the SG97 study sites. The compiled data will include geologic maps (digital and paper), groundwater level maps, and hopefully a reasonable number of historical well records. Field work will involve 1 week of site reconnaissance during June 97 (to be determined) including photographing all stream gaging stations, soil moisture sites, important landforms, geologic outcrops or other features of hydrologic interest. The hydrogeologic data base along with the site photos will be put on a CD-Rom and made available to all investigators. Christopher Duffy will initially work with Doug Miller who has the soils data compiled. The overall objective is to get at least a baseline of information on groundwater response during the experiment and to get some notion of the historical spatial and temporal variability in groundwater levels.

Sponsor(s): NASA/ ARO

References: A Two-State integral-balance model for soil moisture and groundwater dynamics in complex terrain, WRR, 32(8), 2421-2434, 1996.

12. SAMPLING PROTOCOLS (refinements added as available)

12.1 Gravimetric Surface Soil Moisture

Two types of sampling designs will be employed, Field and Profile. The actual soil moisture sampling is the same but the distribution and number of samples is different.

Before getting started each person should establish their average pace in meters. This can be done beforehand (strongly suggested), however, a measured distance will be available at each area for this purpose. Obviously the actual pace in a field will vary with obstacles encountered. The pace is used to aid in distributing samples, not for precise location so do your best to adjust.

12.1.1. Field Sites.

The goal of this sampling is to characterize the mean of what we hope is a "homogeneous" field. A total of 12 points in each field will be sampled. For each field, an orientation and starting point will be determined based upon individual field characteristics and flightline orientation. The general layout is shown in ***Figure 17*** (in some cases this orientation may be rotated 90^o.

All sampling will be done by teams of two for safety and in some cases efficiency. This doesn't mean the team has to sample together, it means that they are in close proximity in case there is problem. Sampling will be conducted every day except when it is raining. The procedure follows:

Sample tins come in boxes of 36. Use cans sequentially, this always helps resolve discrepancies. A box can be used for more than one site but never use two different boxes for a site. Be careful not to spill the cans and try to keep them in a shaded location after collection. Note that the field notebooks will be turned in to the experiment, if you want to keep your own records or make copies of your own sites either make a duplicate set of notes or zerox.

The procedure for surface gravimetric soil moisture sampling follows.

1. Check in at designated coordination location (i.e. Chickasha Office) at standard time that will be established.
2. Pick up sampling kit (use the same kit each day)
   - Bucket
   - Sampling tool (0-5 cm scoop)
   - Large spatula
   - Small spatula

Notebook and pen
Cans

3. Conduct sampling for each field and point
   Remove vegetation and litter
   Use the large spatula to cut a vertical face at least 5 cm deep ***(Figure 18a)***
   Use the scoop to take the sample, small spatula aids sample removal ***(Figure 18b)***
4. Record the following information in the notebook, always use a new page for each Day-Site
   Date
   Site
   Names of samplers
   Start time-Finish time
   Drawing indicating the nominal location of the samples by can number and any relevant landmarks
5. When you return to the lab check in and weigh your samples, recording the field, date, can number and weight on the Gravimetric Soil Moisture sheets
6. Place samples in oven
7. Leave the data sheets in lab

12.1.2. Profile Sites

These are locations at which the objective is solely to correlate gravimetric surface soil moisture to the data collected by the insitu heat dissipation 5 cm sensors. Nine samples are collected on a nominal grid 10 m apart (total of 20 m by 20 m area) immediately adjacent to the sensor enclosure.

12.2. Soil Bulk Density (USDA ARS Hydrology Lab)

All sites involved in gravimetric soil moisture sampling will be characterized for soil bulk density. The method used is a volume extraction technique that has been employed in most of the previous experiments and is especially appropriate for the surface layer. Four replications are made for each site.

12.2.1. The Bulk Density Apparatus

The Bulk Density Apparatus itself consists of two parts. A 12" diameter plexiglass piece with a 6" diameter hole in the center and three 3/4" holes around the perimeter. Foam is attached to the bottom of the plexiglass. The foam is three inches high and two inches thick. The foam is attached so that it follows the circle of the plexiglass. ***Figure 19*** shows the basic components.

Other Materials Required for Operation

* Three 12" threaded dowel rods and nuts are used to secure the apparatus to the ground.
* A hammer or mallet is used to drive the securing rods into the ground.
* A bubble level is used to insure the surface of the apparatus is horizontal to the ground.
* A trowel is used to break up the soil and to remove the soil from the hole.
* Oven-safe kitchen bags are used to hold the soil as it is removed from the ground. The soil is left in the bag when it is dried in the oven.
* Water is used to determine the volume of the hole.
* A plastic gasoline can is used to carry the water to the site.
* One gallon plastic storage bags are used as liners for the hole and to hold the water.
* A 1000 ml graduated cylinder is used to determine the volume of the water. Plastic is best because glass can be easily broken in the field.
* A hook-gauge is used to insure water fills the apparatus to the same level each time.

12.2.2. Selecting and Preparing an Appropriate Site

1. Select a site. An ideal site to conduct a bulk density experiment is: relatively flat, does not include any rock or roots in the actual area which will be tested and has soil which has not been disturbed.
2. Ready the site for the test. Remove all vegetation, rocks and other debris from the surface prior to beginning the test. Remove little or no soil when removing the debris.

12.2.3. Bulk Density Procedure

Securing the Apparatus to the Ground

1. Place the apparatus foam-side-down on the ground.
2. Place the three securing rods in the 3/4" holes of the apparatus.
3. Drive each dowel into the ground until they do not move easily vertically or horizontally. ***(Figure 19a)***

Leveling the Apparatus Horizontally to the Ground

1. Tighten each of the bolts until the apparatus appears level and the foam is compressed to 1-1/2" to 2".
2. Place the bubble level on the surface of the apparatus and tighten and loosen the bolts in order to make the surface level. (If the bubble is too far to the right, the right side is too high. Tighten the bolt(s) on the right, or loosen those on the left, until it is horizontal.)
3. Place the level in at least three directions and on three different areas of the surface of the apparatus.

Determining the Volume from the Ground to the Hook Gauge

1. Pour one liter of water into the graduated cylinder
2. Pour some of the water into a plastic storage bag.
3. Hold the plastic bag so that the water goes to one of the lower corners of the bag.
4. Place the corner of the bag into the hole. Slowly lower the bag into the hold allowing the bag and the water to snugly fill all of the crevasses.
5. Slightly raise and lower the bag in order to eliminate as many air pockets as possible.
6. Lay the remainder of the bag around the hole.
7. Place the hook-gauge on the surface of the apparatus, so that it is secure between the notches on the opposite sides of the hole.
8. Add water to the bag until the surface of the water is just touching the bottom of the hook on the hook-gauge. A turkey-baster works very well to add and subtract small volumes of water. Be sure not to leave any water remaining in the turkey-baster. ***(Figure 19b)***
9. Place the graduated cylinder on a flat surface. Read the cylinder from eye-level. The proper volume is at the bottom of the meniscus. Read the volume of the water remaining in the graduated cylinder. Subtract the remaining volume from the original 1000 ml to find the volume from the ground surface to the hook-gauge.
10. Carefully transfer the water from the bag to the graduated

cylinder. Hold the top of the bag shut, except for two inches at either end. Then use the open end as a spout. (It is best to reuse water, especially when doing multiple tests in the field.)

Loosening the Soil and Digging the Hole

1. Label the oven-safe bag with the date and test number and other pertinent information using a permanent marker.
2. Loosen the soil. The hole should be approximately six inches deep and should have vertical sides and a flat bottom. (The hole should be a cylinder: with surface area the size of the hole of the apparatus and height of six inches.)
3. Remove the soil from the ground and very carefully place it in the oven-safe bag. (Be careful to loose as little soil as possible.) ***(Figure 19 c and d)***
4. Continue to remove the soil until the hole fits the qualifications.

Finding the Volume of the Hole

1. Determine the volume from the bottom of the hole to the hook-gauge as described in **Determining the Volume from the Ground to the Hook-Gauge**. Reusing the water from the prior measurement presents no potential problems and is necessary when performing numerous experiments in the field.
2. Subtract the volume of the first measurement from the second volume measurement. The answer is the volume of the hole.

Calculating the Density of the Soil

1. Dry the soil in an oven for at least 24 hours.
2. Mass the soil.
3. Divide the mass of the soil by the volume of the hole. The answer is the density of the soil.

12.2.4. Potential Problems and Solutions

After I started digging I hit a rock. What should I do?

The best solution is to start over in another location. Also, you can remove the rock from the soil and subtract the volume of the rock from the total volume of the water. You should never include a rock in the density of the soil. Rocks have significantly higher densities than soil and will invalidate the results. Roots, corn cobs, ants and even mole holes will also invalidate the results. If you find any of these things the best thing to do is start the test again at another site.

After I began digging the hole I noticed one of the dowels wasn't the

apparatus firmly in place. Do I have to start over?

Unfortunately, if you have already started digging you do have to start the experiment again. Replacing the dirt to find the volume between the ground surface and the hook-gauge will give an inaccurate volume and thus an inaccurate soil density.

I noticed that the bag holding the water has a small leak. Is there anything I can do? If the leak began after you had already found the volume, it is not necessary to start again. The volume is being measured in the graduated cylinder. If you have already removed the appropriate volume of water leaks in the bag, it will not affect the results of the test. However, if you noticed the leak before finding the volume, you will have to start again.

12.3. Vegetation Sampling

1. Identify site (field) that exceeds minimum size requirements.
2. Determine vegetation type and phenological stage measure plant height
3. Take vertical photograph and oblique photographs of sample area.
4. Clip standing vegetation in 0.5 m2 sample area, bag, and weigh. (Standing Wet Biomass).
5. Gather liter on the soil surface, bag, and weigh. (Litter Wet Biomass)
6. Measure fraction absorbed PAR in a 10 m radius surrounding the sample area.
7. Measure LAI with Plant Canopy Analyzer in a 10 m radius surrounding the sample area.
8. Dry vegetation and litter samples in drying ovens and weigh. Standing Dry Biomass; Litter, Dry Biomass.
9. Separate green and brown leaves, weigh separately. Green Standing Dry Biomass; Brown, Standing Dry Biomass

13. LOCAL INFORMATION

13.1. Motels

Oklahoma City, OK

Embassy Suites Hotel (Aircraft Briefing Hotel)
1815 South Meridian
Oklahoma City, OK 73108
(405) 682-6000

20 suites have been reserved under the name "USDA" at a rate of $60.00 per suite, per night, plus tax (government employees would be exempt from 2% of the tax by filling out a tax exemption form available at the front desk. This is based on a minimum length of stay of 25 consecutive nights. If staying less than 25 nights, the rate could go to $70.00 per night plus tax. Reservations should be made no later than June 3, 1997. The special rate will not be available after this date. The Embassy Suites offer a full complimentary breakfast each morning.

Hampton Inn (an option for shorter stays and next door to the Embassy Suites)
1905 S. Meridian Avenue
Oklahoma City, OK 73108
(405) 682-2080

Government rate - $62.00/night with government American Express card
Non-Government rate - $62.00/night plus tax (10.375%)
Continental breakfast provided

Chickasha, OK

Days Inn (looks like the best deal in Chickasha-ask for upstairs on extended stay)
2701 S 4th Street
Chickasha, OK 73018
(405) 222-5800

Government - $35.00 night (no tax)
Non-government - $35.00/night plus tax
Extended stay - $30.00/night

Best Western Inn (the only place I've ever stayed, easy walking to stores and rest.)
2101 S 4th Street
Chickasha, OK 73018
(405) 224-4890
Government and non-government rate - $39.00 /night plus tax

El Reno, OK

Ramada Limited (looks like the best option for El Reno)
Exit 125, Route 40
El Reno, OK 73036
(405)262-1022

Government rate - $38.00/night plus tax (ask for Norma)
Non-government rate - $42.00/night plus tax
(will give each guest 1 night free for each week of occupancy)
Full continental breakfast provided

Best Western Inn at Hensley's
I-40 & Country Club Road
El Reno, OK 73036
(405) 262-6490

Government rate - $40.00/night (includes tax)
Non-government rate - $48.53 (includes tax)
Full breakfast provided

13.2. Maps

Several maps are provided here for orientation purposes. ***Figure 20*** is a regional map, ***Figure 21*** is a map of Chickasha, OK, ***Figure 22*** is a map of the El Reno area, and ***Figure 23*** is the area of Lamont and Ponca City.

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15. LIST OF PARTICIPANTS

The following list includes all people participating in data collection activities on site during SGP97. Column 4 indicates the type of activity (1=aircraft, 2=site characterization, and 3=soil moisture sampling, 4=flux stations). Column 5 indicates the likely area for the person (1=Chickasha, 2=El Reno, 3=Central Facility, 4=OKC). Column 6 is used to indicate when two individuals will fill a particular position. Columns 7, 8, 9 and 10 indicate the weeks of participation.

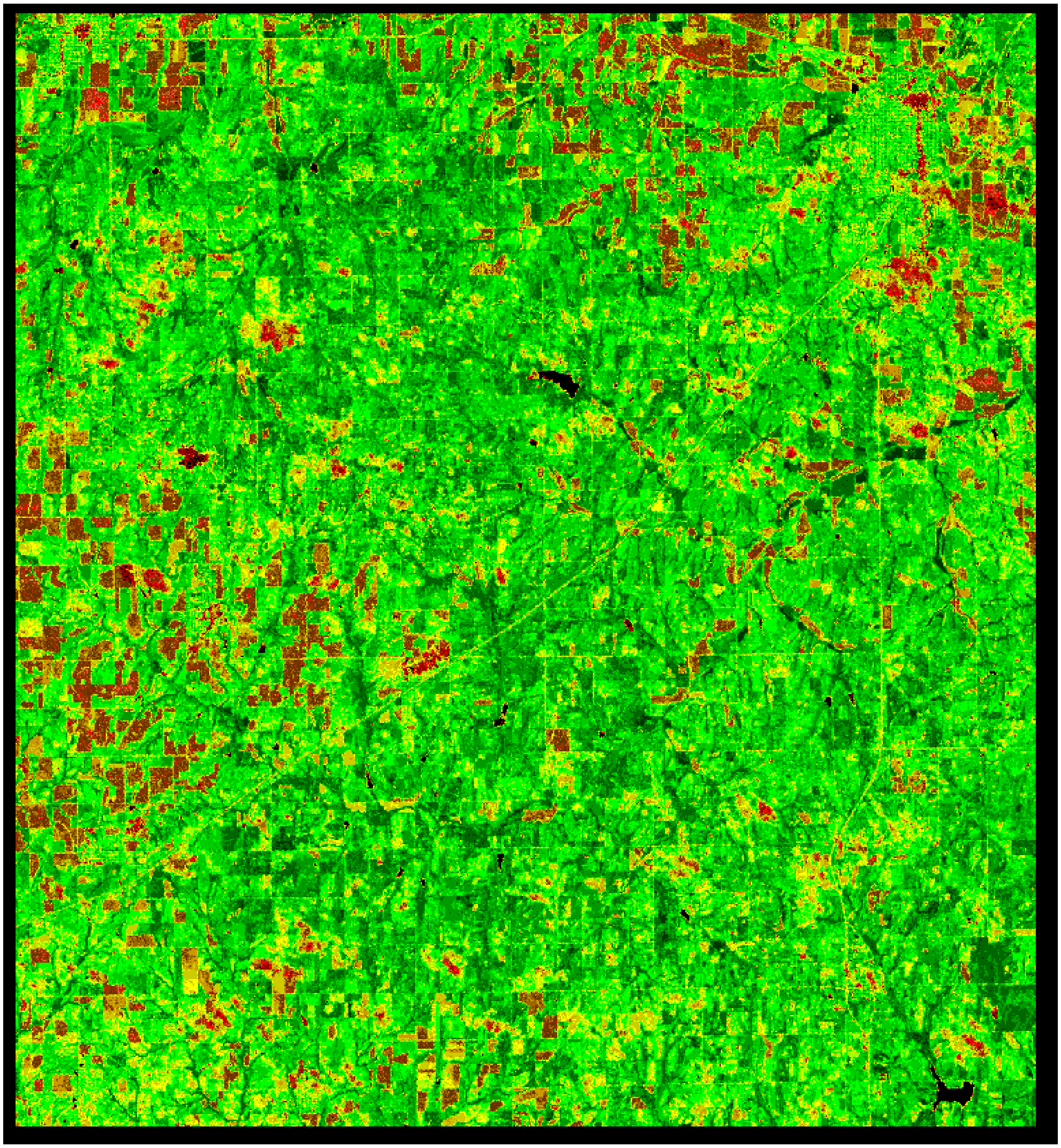
	1	2	3	4	5	6	7	8	9	10	11	12
							Week					
	Last	First	Affiliation				1	2	3	4	email	Phone
1	Wei	Ming Ying	NASA HQ		4		x	x			ming-ying.wei@hq.nasa.gov	(202) 358-0771
2	Jackson	Thomas J.	USDA ARS Hydrology Lab		4		x	x	x	x	tjackson@hydrolab.arsusda.gov	(301) 504-8511
3	Mahrt	Larry	Oregon State Univ.		4	a	x				mahrt@ats.orst.edu	(541) 737-5691
4	Entekhabi	Dara	MIT		4	a		x	x	x	darae@mit.edu	(617) 253-9698
5	Bradfield	Peter	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
6	Crew 1	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
7	Crew 2	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
8	Crew 3	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
9	Crew 4	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
10	Crew 5	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
11	Pilot 1	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
12	Pilot 2	P3	NASA Wallops	1	4		x	x	x	x	Peter.N.Bradfield.1@gsfc.nasa.gov	(757) 824-1292
13	Le Vine	David	NASA GSFC	1	4		x	x	x	x	dmlevine@mrneg.gsfc.nasa.gov	(301) 286-8059
14	Hsu	Ann	NASA GSFC	1	4		x	x	x	x	hsu@hydro.gsfc.nasa.gov	(301) 286-8099
15	Isham	John	Univ. of Massachusetts	1	4		x	x	x	x	isham@alex.ecs.umass.edu	(413) 545-0880
16	Knapp	Eric	Univ. of Massachusetts	1	3		x				knapp@alex.ecs.umass.edu	(413) 545-4699
17	Xia	Yuan	Univ. of Massachusetts	1	4		x	x	x	x	xia@alex.ecs.umass.edu	(413) 545-4635
18	Moore	Al	NASA LaRC	1	4		x				a.s.moore@larc.nasa.gov	(757) 864-7094
19	Lenschow	Don	NCAR	1	4	b	x	x			lenschow@elder.mmm.ucar.edu	(303) 497-8903
20	Davis	Ken	Univ. of Minnesota	1	4	b			x	x	davis@gis.min.edu	(612) 625-2774
21	Browell	Ed	NASA LaRC	1	4	c	x	x			E.V.Browell@larc.nasa.gov	(757) 864-1273
22	Ismail	Syed	NASA LaRC	1	4	c			x	x	S.ISMAIL@LaRC.NASA.GOV	(757) 864-2719
23	Kooi	Susan	NASA LaRC	1	4		x	x	x	x	s.a.kooi@larc.nasa.gov	(757) 864-2711
24	Matthews	Leroy	NASA LaRC	1	4		x	x	x	x	L.F.MATTHEWS@LaRC.NASA.GOV	(757) 864-7564
25	Edwards	William	NASA LaRC	1	4	d			x	x	W.C.EDWARDS@LaRC.NASA.GOV	(757) 864-1632
26	Insley	George	NASA LaRC	1	4	d	x	x			G.V.INSLEY@LaRC.NASA.GOV	(757) 864-1555

27	MacPherson	Ian	NRC	1	4		x	x	x	x	Ian.Macpherson@nrc.ca	(613) 998-3014
28	Pilot	NRC	NRC	1	4		x	x	x	x	Ian.Macpherson@nrc.ca	(613) 998-3014
29	Bastian	Matthew	NRC	1	4		x	x	x	x	Ian.Macpherson@nrc.ca	(613) 998-3722
30	Crawford	Tim	NOAA ATDD	1	4		x	x	x	x	crawford@atdd.noaa.gov	(423) 576-0452
31	Pilot	Long-EZ	NOAA ATDD	1	4		x	x	x	x	crawford@atdd.noaa.gov	(423) 576-0452
32	Schmugge	Thomas	USDA ARS Hydrology Lab	1	4			x			schmugge@hydroilab.arsusda.gov	(301) 504-8554
33	Pilot	DOECitation	DOE	1	4			x				
34	Operator	TIMS	DOE	1	4			x				
35	Gray	Lawrence	ISTS	1	4			x			gray@isl.ists.ca	(416) 665-5485
36	Pilot	PSRO	ISTS	1	4			x			gray@isl.ists.ca	(416) 665-5485
37	Doriaswamy	Paul	USDA ARS RSML	2	1			x	x	x	pdoraisw@asrr.arsusda.gov	(301) 504-6576
38	Ward	Alan	USDA ARS RSML	2	1			x	x	x		(301) 504-7614
39	Daughtry	Craig	USDA ARS RSML	2	1			x			cdaughtry@asrr.arsusda.gov	(301) 504-5015
40	Dulaney	Wayne	USDA ARS RSML	2	1			x	x	x		(301) 504-6076
41	Russ	Andrew	USDA ARS RSML	2	1			x	x	x		(301) 504-7614
42	Curry	Troy	USDA ARS RSML	2	1			x	x	x		(301) 504-7614
43	Luman	Nate	USDA ARS RSML	2	1			x	x	x	stu960562@boaz.gcc.edu	(301) 504-7614
44	Grothe	Jan	USDA ARS RSML	2	1			x	x	x	jg1187@mcis.messiah.edu	(301) 504-7614
45	Luman	Jon	USDA ARS RSML	2	1			x	x	x		(301) 504-7614
46	Hollinger	Steve	Ill. St. Water Survey	2	1			x	x	x	hollingr@uiuc.edu	(217) 244-2939
47	Chauhan	Narinda	NASA GSFC	2	1			x	x	x	nsc@fire.gsfc.nasa.gov	(301) 286-1757
48	Fahsi	Ahmed	Alabama A&M Univ.	2	1			x	x		afahsi@asnaam.aamu.edu	(205) 851-5075
49	Mohanty	Binayak	USDA ARS SL	2	1	e	x				bmohanty@ussl.ars.usda.gov	(909) 369-4852
50	Shouse	Peter	USDA ARS SL	2	1	e	x	x		x	pshouse@ussl.ars.usda.gov	(909) 369-4849
51	Jobes	Jack	USDA ARS SL	2	1	e	x				jjobes@ussl.ars.usda.gov	(909) 369-4883
52	Russel	Walter	USDA ARS SL	2	1	e		x	x		wrussell@ussl.ars.usda.gov	(909) 369-4850
53	Tsegaye	Teferi	Alabama A&M Univ.	2	1		x	x			ttsegaye@asnaam.aamu.edu	(205) 851-5075
54	Manu	Andrew	Alabama A&M Univ.	2	1				x		amanu@asnaam.aamu.edu	(205) 851-5075
55	Narayan	Rajbhandari	Alabama A&M Univ.	2	1					x		(205) 851-5075
56	McKee	Lynn	USDA ARS Hydrology Lab	2	1			x	x	x		(301) 504-7490
57	Famiglietti	Jay	Univ. of Texas Austin	3	1		x	x	x	x	jfamiglt@maestro.geo.utexas.edu	(512) 471-3824
58	Bartelmann	Monika	Univ. of Texas Austin	3	1		x	x	x	x		(512) 471-3824
59	Branstetter	Marcia	Univ. of Texas Austin	3	1		x	x	x	x		(512) 471-3824
60	Devereaux	Johanna	Univ. of Texas Austin	3	1		x	x	x	x		(512) 471-3824
61	Devlin	Karen	Univ. of Texas Austin	3	1		x	x	x	x		(512) 471-3824
62	Graham	Steve	Univ. of Texas Austin	3	1		x	x	x	x		(512) 471-3824
63	Rodell	Matt	Univ. of Texas Austin	3	1		x	x	x	x		(512) 471-3824

64	GS1	AAMU	Alabama A&M Univ.	3	1	f	x	x				(205) 851-5075
65	GS2	AAMU	Alabama A&M Univ.	3	1	f			x	x		(205) 851-5075
66	GS3	AAMU	Alabama A&M Univ.	3	1	g	x	x				(205) 851-5075
67	GS4	AAMU	Alabama A&M Univ.	3	1	g			x	x		(205) 851-5075
68	Student 2	UCinn	University of Cincinnati	3	3	h			x	x	sislam@fractals.cee.uc.edu	(513) 556-1026
69	Student 1	UCinn	University of Cincinnati	3	3	h	x	x			sislam@fractals.cee.uc.edu	(513) 556-1026
70	Chen	Ji	Univ. of Illinois	3	3	i			x	x	jichen@uiuc.edu	(217) 333-0687
71	Saco	Patricia	Univ. of Illinois	3	3	i	x	x			saco@uiuc.edu	(217) 333-0687
72	Heathman	Gary	USDA ARS GRL	3	1	j	x	x	x	x	gheathman@uoknor.edu	(405) 224-7393
73	Verser	Alan	USDA ARS GRL	3	1	j	x	x	x	x		(405) 224-7393
74	Smith	Mark	USDA ARS GRL	3	1	k	x	x	x	x		(405) 224-7393
75	Few	Roy	USDA ARS GRL	3	1	k	x	x	x	x		(405) 224-7393
76	van Oevelen	Peter	WAU	3	2		x	x	x	x	Peter.vanOevelen@users.whh.wau.nl	
77	Houser	Paul	NASA GSFC	3	2		x	x	x	x	houser@hydro4.gsfc.nasa.gov	(301) 286-7702
78	Miller	Doug	Penn State Univ.	3	1		x	x	x	x	miller@essc.psu.edu	(814) 863-7207
79	Kim	Gwanseob	TAMU	3	1		x	x	x	x	lynette@civil.tamu.edu	(409)862-1542
80	Wickel	Bart	USDA ARS Hydrology Lab	3	2		x	x	x	x		(301) 504-7490
81	Moy	Linda	USDA ARS Hydrology Lab	3	2		x	x	x	x		(301) 504-7490
82	Wigglesworth	Micheal	USDA ARS Hydrology Lab	3	2		x	x	x	x		(301) 504-7490
83	Bindlish	Rajat	Penn State Univ.	3	1		x	x	x	x	bindlish@essc.psu.edu	(814) 863-8609
84	Lohman	Dag	Princeton Univ.	3	2	l	x	x			efwood@princeton.edu	(609) 258-2799
85	Crow	Wade	Princeton Univ.	3	2	l			x	x	efwood@princeton.edu	(609) 258-2799
86	Levine	John	Boston University	3	2	m	x	x			jblevi@bu.edu	(617) 353-6790
87	Amano	Etsuko	Boston University	3	2	m			x	x	amano@bu.edu	(617) 353-6790
88	O'Neill	Peggy	NASA GSFC	3	3		x	x	x	x	hsu@hydro4.gsfc.nasa.gov	(301) 286-8273
89	Fuchs	John	NASA GSFC	3	3		x	x	x	x		(301) 286-8273
90	Student 1	OSU	Okla. State University	3	3		x	x	x	x	relliot@agen.okstate.edu	(405) 744-8423
91	Student 2	OSU	Okla. State University	3	3		x	x	x	x	relliot@agen.okstate.edu	(405) 744-8423
92	Student 3	OSU	Okla. State University	3	3		x	x	x	x	relliot@agen.okstate.edu	(405) 744-8423
93	Harlow	Chawn	Univ. of Arizona	3	2		x	x	x	x	chawn@hwr.arizona.edu	(520) 621-1378
94	Burke	Eleanor	Institute of Hydrology	3	2		x	x	x	x	E.Burke@ioh.ac.uk	4401491838800
95	IH	IH	Institute of Hydrology	3	2		x	x	x	x	E.Burke@ioh.ac.uk	
96	Kustas	Bill	USDA ARS Hydrology Lab	4	2	n	x	x			bkustas@hydrolab.arsusda.gov	(301) 504-8498
97	Prueger	John	USDA ARS NSTL	4	2	n			x	x	prueger@nstl.gov	(515) 294-7694
98	Sauer	Tom	USDA ARS SPA	4	2	n	x				tsauer@comp.uark.edu	
99	Peters-Lidard	Christa	Georgia Tech	4	1		x	x	x	x	cpeter@ce.gatech.edu	(404) 894-5190
100	Starks	Pat	USDA ARS GRL	4	2		x	x	x	x	pstarks@grl1.ars.usda.gov	(405) 262-5291

Normalized Difference Vegetation Index (NDVI)

Image of the Washita, OK Site, Landsat TM image for July 9th, 1991

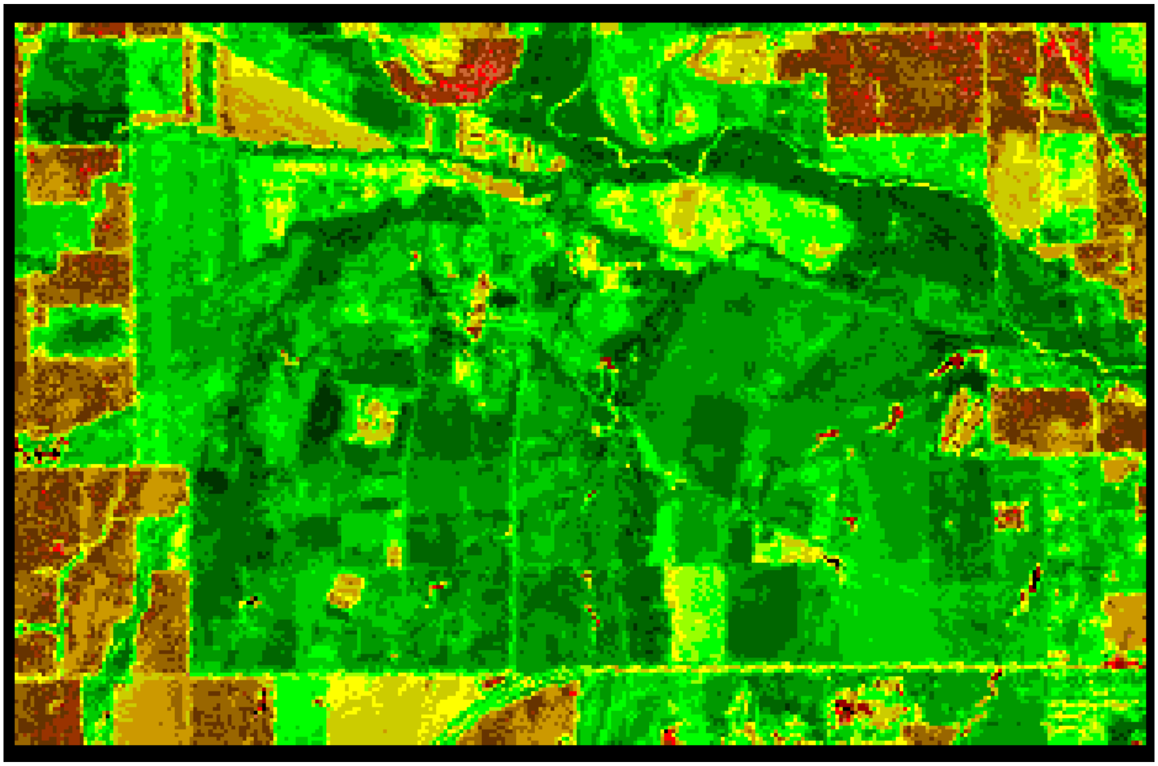


NDVI Scale

Bare Soil/Sparce Green Vegetation | **Dense Green Vegetation**

Normalized Difference Vegetation Index (NDVI)

Image of the El Reno Site, Landsat TM image for July 9th, 1991



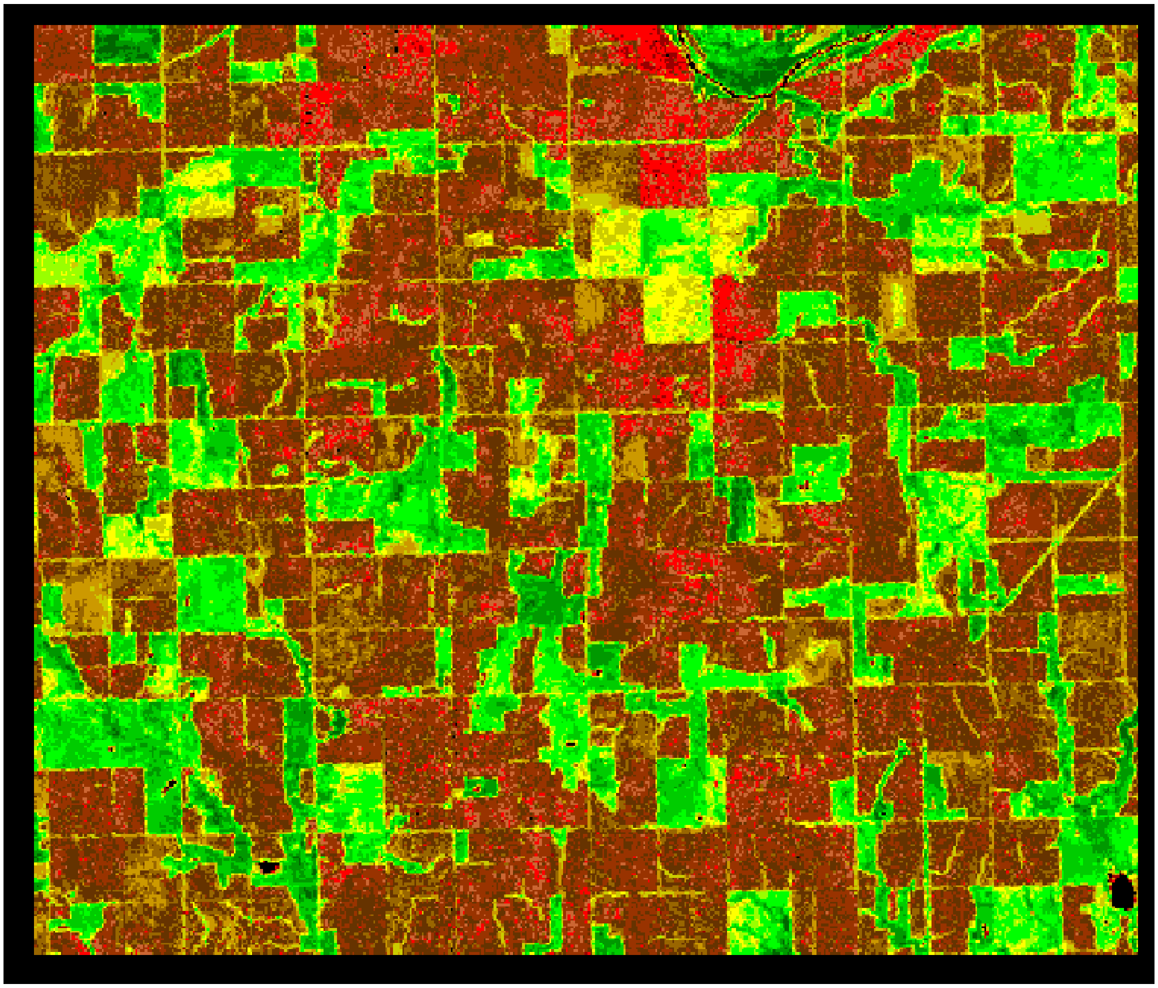
NDVI Scale

Bare Soil/Sparce Green Vegetation

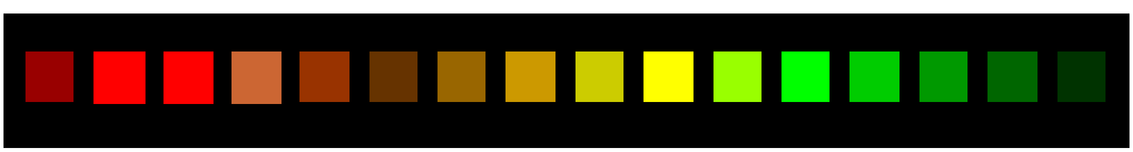
Dense Green Vegetation

Normalized Difference Vegetation Index (NDVI)

Image of the ARM Site, Landsat TM image for July 9th, 1991



NDVI Scale



Bare Soil/Sparce Green Vegetation **Dense Green Vegetation**